MECHANICAL APTITUDE

JOHN W. COX

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ITS EXISTENCE, NATURE AND MEASUREMENT

BY

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PREFACE

THE research described in the following pages was carried out at the Psychological Laboratory of University College, London. Its aim—a psychological study of what has been called 'mechanical ability' or the 'mechanical sense'—divides naturally into two parts, viz. (1) a qualitative one concerning the psychological nature of this 'ability', and (2) a quantitative one concerning the way in which it may be rightly said to exist and be measured.

The former—qualitative—part of the problem has involved the introspective analysis of a variety of tests. My best thanks are due to all who have been good enough to undergo the tests for this purpose, and especially to Mr. J. C. Flugel, Mr. H. S. Perera, and Dr. Ll. Wynn Jones for their very full and helpful introspections.

To pursue the quantitative side of the problem it was necessary to give the tests to a large number of subjects, both trained and untrained in engineering work. Here I would tender thanks to Mr. F. Charles, Head Master of the Day School, City of London College, for permission to carry out some of the earlier work at his school; to the L.C.C. Education Committee and to Mr. W. H. A. Dockerill, Head Master of the Kenmont Gardens L.C.C. (Boys) School, for similar permission to give the tests to pupils of the latter school. I have also to thank Mr. Dockerill and his staff for much valuable information regarding their pupils. The final experiments were carried out at the Boys' Wing School, R.A.F., Cranwell,

by the kind permission and arrangement of Colonel I. Curtis, Educational Adviser to the Air Ministry, and Mr. H. A. Cox, Head Master of the School. To Colonel Curtis I am also indebted for the valuable data respecting his own Mental Efficiency Test, and the Passing Out Examination, which are here published by permission of the Air Council. For help in checking calculations and correcting proofs I have to thank Miss D. Draycon and my wife.

Above all I wish to acknowledge my debt to Professor C. Spearman, whose helpful suggestion and criticism has been freely given throughout. Without the two instruments of research which he has supplied, namely the criterion for a single common factor, and the principles of cognition, the successful prosecution of the problem would have been impossible.

J. W. C.

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MECHANICAL APTITUDE

CHAPTER I

INTRODUCTORY

SOCIAL IMPORTANCE OF MECHANICAL INVENTION

THE twentieth-century civilized man, faced with the products of mechanical invention at almost every turn, will need no argument to convince him how greatly he depends for his material comfort and prosperity on the mechanical genius of his age. This alone would render the work of the engineer worthy of our admiration and respect, and would fully justify any attempt to bring psychological knowledge and experiment to bear on some of the problems of this great industry. But there is an even greater good which this same genius may take to its credit, namely the uplifting influence it has exercised on social life. This debt which man's higher spiritual welfare owes to mechanical invention may be less evident, but is no less real. To appreciate something of it we have but to reflect for a moment on the far-reaching effects which such inventions as the steam engine and the printing press have had on the minds and social activities of the people.

Some inventions, like the artificial limb and the cleverly devised surgical instrument, have been directly enlisted in the cause of humanity; others, like the telescope,

have greatly increased man's knowledge; while others, yet again, such as the locomotive, have so enriched man's experience as to contribute in no small measure to his education and social development. Even those inventions which seem to serve merely his material needs have eased the struggle for existence, and so afforded him greater leisure in which to develop his higher spiritual life. Clearly, then, mechanical invention not only promotes material prosperity—important as this may be; it also subserves man's higher ethical purposes.

If further evidence of the debt which society owes to mechanical invention is needed, it is provided by the fact that not only our present prosperity and progress, but our very civilization itself, rests on man's ability to tap, and turn into useful channels, the natural sources of energy around him. This, in the majority of cases, means converting such energy into mechanical energy. The great material advance of the last hundred years has been almost entirely due to the invention of mechanical devices whereby the enormous energy dormant for centuries in our coal-fields could be harnessed to the service of mankind. Evidence of the far-reaching effects on social life which man's accession to this vast power has brought about, is to be found on every side—in the cheap books which have facilitated popular education, and the newspapers which have made possible a rapid interchange of ideas and opinions, in the factories which have created large towns with all the advantages of corporate life, and in the greatly improved standard of living generally. In the case of our greatest mechanical invention—the steam engine—its influence on the life of the people can hardly be overrated. Indeed, one authority has gone so far as to say: 'The conversion of thermal energy into mechanical energy, first practically effected by the invention of the steam engine, has brought about in a single century more permanent change in the manner of living, and even in the habits of thought of the inhabitants of the world, than

any combination of political, social, or personal influences could have effected.' [1]

THE HUMAN FACTOR IN ENGINEERING

Efficiency. The foregoing reflections make it evident that engineering can justly claim a unique and important place among the industries of the country; so much so that it is our duty, as a nation, to spare no pains in maintaining the highest possible standards of efficiency in it. Among the most potent influences which determine such efficiency are those of a psychological nature; and of these, the capacity of the worker for the kind of work he is called upon to do is one of the most important.

Variety of Occupation. In engineering, this latter, human, factor assumes a special importance on account of the great variety of occupations which fall within the scope of the industry. These frequently differ from one another with respect to the mental and manual operations, and the technical knowledge, which they entail. Hence there would appear to be great need for vocational guidance and selection if the industry is to make the most effective use of its workers. But before such guidance can be given, vocational psychology must considerably enlarge its knowledge of the particular aptitudes upon which success at these various occupations may depend.

Originality and Invention. Of such aptitudes, those which may be found to underlie the higher intellectual and creative work in engineering would seem, for several reasons, to merit the closest study and attention. In the first place, this industry differs from all others in being obliged to invent and make the very machines and tools which it uses. Moreover, it must supply suitable machinery to those other industries whose prosperity is now closely dependent on the employment of mechanical devices. It is therefore essential not only to its own welfare, but also

[1] Prof. Soddy, in *Matter and Energy*, p. 240.

to that of other industries, that the engineering profession should include within its ranks men who are able to supply this need.

Secondly, an object cannot be made until it is invented. Consequently although the number employed on purely creative work may be relatively few, their work is the very breath of life to the rest.

Again, there are many kinds of engineering work which, although not primarily creative, demand an insight into mechanical movement, and require of the worker a certain degree of resourceful thinking not entirely unlike mechanical invention itself. The draughtsman, the turner, the fitter, the worker in the repairs shop, the salesman, and even the machine operative, must at times profit by a ready grasp of the movements involved in the mechanical objects with which their work is associated. Such understanding and insight has been attributed by some to a special 'mechanical sense', a study of which forms the subject of the research described in this book. Without considering here whether such a 'sense' exists as a special aptitude, it evidently has much in common with mechanical invention.

What has been said above about the work of the engineer applies largely to that of the engineering student. Much of the latter's time is naturally devoted to a study of the engineering sciences in which, among other things, he is asked to acquire a knowledge of mechanical laws and mechanical movements. Such work, especially on its technical and practical sides, involves the understanding and employment of scientific apparatus, machines and tools. Much of the thinking which the student is called upon to do must therefore relate to mechanical objects.

Finally, we may look to our great engineers and ask what quality of mind was it that made them great. Their greatness, as engineers, must be attributed, primarily, to their ability as original and ingenious thinkers in the field of mechanical invention. Other important qualities

of intellect and character they undoubtedly possessed, but these alone could hardly have differentiated them from the great in other walks of life.

NEED FOR RESEARCH

Vocational Guidance. The mere fact of seeing that much of the work of the engineer calls for an insight into the working of mechanical objects, and a certain measure of constructive and original thinking about mechanisms, does not enable us to postulate, forthwith, the existence of a special unitary power of mind which may be labelled 'mechanical ability', or 'mechanical ingenuity', or the 'mechanical sense'. It is one thing to examine a piece of work—the mind's finished product—and see that it differs from other work in being ingenious, original, etc., but quite another to determine whether this work needs, for its execution, a special aptitude. However strikingly original or ingenious a piece of mechanism may be, this fact in itself can never inform us how far the mind that produced it owed its power to a special 'mechanical sense', and how far to high 'general intelligence', training, and experience. Neither can it tell us how the 'originality' that went to produce it is related to that needed to conceive a great work of art, or to plan a new system of social reform. Only by a careful study of the mental activity in question, accompanied by psychological experiments especially planned to answer these questions, can we hope to arrive at this kind of knowledge. The vital importance of such knowledge for vocational guidance and selection is obvious. Until we know what are the special aptitudes it is impossible to estimate even the possibilities of vocational guidance, much less employ it with any hope of success.

School Work. A psychological study of the special aptitudes that may be involved in engineering is amply justified in the light of what has already been said. Its urgency is rendered greater by the fact that neither in

the elementary and secondary schools nor perhaps even in the technical schools does that kind of intellectual work which we have seen to be essential in engineering appear to receive the attention that its importance warrants.

In the case of the elementary and secondary schools, the various subjects of the curricula, as usually taught, provide little exercise for the kind of mechanical understanding and insight to which we have referred. Consequently there is little opportunity of judging whether a boy passing on to a course of training for engineering is really fitted to undertake such work. This makes it all the more necessary to discover what are the special aptitudes (if any) involved, so that if these are not ordinarily called for in school work greater provision for their exercise and development may be made in future.

In the case of the technical schools, although, as we have seen, much of the work naturally involves a certain measure of thought about mechanical things, it is only incidentally that the student is thrown upon his own resource and ingenuity. On the theoretical side of his course he is required to assimilate the ideas involved in a study of the engineering sciences, and to acquire a working knowledge of their underlying principles; while on the practical side, much of his time is occupied in the execution of standard exercises carried out after a practical demonstration by the instructor. Such work must depend on a variety of factors. Among them the special aptitudes which possibly underlie the intellectual and creative side of engineering may be, as it were, interwoven, but find little chance of clear and direct expression. Only by knowledge gained through a careful study of the mental processes involved in this kind of work and training, may we hope to give the student more enlightened guidance in his choice of studies and of occupation than seems at present possible.

'*Selection*.' Notwithstanding the great practical value

which a knowledge of the special aptitudes involved in engineering would seem to possess, very little serious work in this direction has been done so far. Hitherto, vocational psychologists have been concerned with the problem of 'selection' rather than that of 'guidance'. To this end they have aimed at discovering tests whereby a person's suitability for a specific occupation might be gauged. However useful such work has been in the selection of applicants for well-defined occupations, it has contributed little to the essential problem of vocational guidance. For the latter purpose, we usually require to determine not merely a person's suitability for certain specified occupations, but his greatest vocational possibilities.

'Faculty' Psychology. Feeling, possibly, the need for knowing what are the mental qualities they should seek to measure, investigators have frequently sought to arrive at these by the simple process of observing the various concrete processes which the worker is called upon to carry out. This has, at times, resulted in an analysis of the vocational requirements into various special 'abilities', 'powers', 'capacities' or 'faculties'. For example, certain work has been seen to require attention, hence the 'capacity' of attention is said to be needed for this. Other work requires imagination and originality, hence a faculty of 'creative imagination', and so on. We have already noticed the falsity of such reasoning. The inadequacy of this sort of analysis, for practical purposes, is seen by the fact that the tests subsequently suggested for the vocation in question are usually chosen, not as tests of the special 'capacities' into which the vocation has been thus analysed, but for their resemblance to the actual operation which the workers are called upon to carry out. In these circumstances, the chief work of introspection has been to observe the similarity between test and 'job'; the further analysis into special 'powers' or 'abilities' appears to have been superfluous and misleading.

Limitations of Introspection. Those who have sought

to discover the nature and existence of special measurable aptitudes by means of subjective analysis alone, have surely placed on introspection a burden greater than it can bear. Introspection is, of course, a valuable instrument. It has assisted in the development of useful tests, especially when the occupational requirements have been somewhat rigidly defined. But it has its limitations. To determine the existence of an 'aptitude' or an 'ability', in respect of which persons differ, and may be measured, it is not enough to know the mental processes involved; we must know how they function with relation to one another, and to the other mental processes. While introspection may exhibit these processes, it can no more disclose to us the laws by which they function, than the observance of moving bodies will disclose the laws by which they move. For this, unfortunately, we must measure and calculate.

A further weakness in introspective analysis is seen when the products of the analysis are expressed in general terms, such as 'imagination', 'judgment', etc. Such may be true, as far as it goes, but tells us little of practical value—there are so many kinds of imagination! By labelling the actual observable processes with these general terms it is doubtful whether we add anything to our knowledge of them, and we come perilously near to the 'faculty' psychology referred to above.

Absence of Criteria. It is true that in using vocational tests psychologists have seldom relied on introspective data alone, but have determined the correlation between the tests and such other estimates of ability as they have been able to obtain. But they have seldom applied to their correlation coefficients the criteria by which alone it is possible to judge what are the 'abilities' (or 'factors') involved in their tests. The fact that two series of measurements correlate signifies no more than that they both measure something in common. What the abilities involved may be, the mere fact of correlation is powerless

to inform us. It has been a frequent source of error to suppose that because a test correlates with an occupation for which it has been specially devised, it measures a special capacity for that occupation. In the absence of the necessary criteria for deciding this, it would often be more reasonable to suppose it to measure 'general intelligence'!

THE APPROACH TO A VOCATIONAL PSYCHOLOGY

The Question. In view of the large amount of effort that has been expended in the kind of work referred to above, it seems a pertinent question to ask whether such work, however useful in other ways, is likely to provide the kind of knowledge needed for a sound system of vocational guidance? The most we can expect it to do, is to provide tests for specific occupations by the 'trial and error' method of eliminating those tests which correlate least, and retaining those which correlate highest, with the occupation in question. The knowledge so gained must, for the most part, be confined to the particular circumstances investigated, and even then can shed little light on the true psychological nature of the mental processes and 'abilities' involved. Out of such empirical knowledge can hardly emerge the ultimate laws and general principles needed to guide and economize future practice.

Moreover, for the higher and more pressing forms of vocational guidance in which it is required to determine whether a person is fitted to train for a given vocation, or to ascertain which vocation he may most suitably enter, a general survey of his whole mentality, rather than his ability to carry out specific occupational tests, is needed. For this purpose we require a fuller knowledge of the special 'abilities' and 'aptitudes' than can be provided by the kind of work we have been considering. By what path, then, may we hope to acquire the necessary knowledge for sound vocational guidance?

Examination of Mind. In the first place, it seems necessary to shift the focus of our attention from the

vocations and occupations to mind itself. Instead of seeking to analyse and measure the requirements of certain occupations, we should first aim at discovering the unitary mental characters (the special 'abilities', 'aptitudes', etc.) with respect to which persons differ, and may be measured. Before, of course, vocational guidance can be given, we must also analyse the vocations in terms of these mental characters; but the former is the prior question, since until we know what these characters are, it is impossible to analyse, appropriately, the vocations.

Experimental Criteria. The existence of such mental characters can only be determined by the aid of experiments especially planned for this purpose. In these, reliable measures of the activities under investigation must be obtained by suitable tests, and such other means as may be possible. To this data, the correlational criteria by which alone it is possible to determine what 'factors' (or unitary measurable mental characters) are present in the activities in question, must be applied. Hence the experiments must be so arranged as to yield the correlation coefficients necessary for this purpose.

Ultimate Analysis. While objective experiment may demonstrate the presence of unitary mental characters, only by introspective analysis can a knowledge of their underlying mental processes be gained. Apart from its intrinsic psychological interest, such knowledge is of the utmost value in the work of devising and improving tests for the particular mental characters concerned, and of analysing the vocations in terms of these characters. Objective experiment must therefore be supplemented by subjective analysis. If this analysis is to be effective, it must resolve the mental activities into their ultimate processes.

Examination of Vocations. Finally, that the work outlined above may bear fruit in the form of vocational guidance, there remains the task of analysing the vocations. Here, as in the analysis of mind, the products of the

analysis must be expressed in terms of known unitary measurable characters, and subjective introspection must be supported by objective experiment. This work of analysing vocations is, of course, complementary to that of analysing mind. Indeed, the double process will frequently go on side by side, the actual occupational activities yielding part of the data for the mental analysis. Thus knowledge of the unitary mental characters with respect to which individuals may be measured, and of the vocations wherein each of these are required, will progress together, the one supporting and enlightening the other.

SCOPE OF THE PRESENT BOOK

The present book is an account of a psychological research, extending over several years, which was carried out in the hope of contributing to vocational psychology, in some small measure, the kind of knowledge which we have seen to form a necessary prelude to scientific vocational guidance. The object of the research has been to inquire into the existence and psychological nature of what has been variously called 'mechanical ability', 'mechanical ingenuity', or the 'mechanical sense'. This work has been pursued along the path outlined in the previous section of this chapter.

The results arrived at bear closely on the problem of vocational guidance and selection in engineering, and especially on that important side of engineering to which attention has already been drawn, namely the intellectual and creative side. New tests have been developed which promise to be of practical service in this connection. The results also have a direct bearing on certain aspects of general and technical education. In the belief that they will, on this account, prove interesting not only to the psychologist but also to the layman, and in particular to those interested in the selection and training of workers in the engineering industry, they have been presented as far as possible in non-technical language.

CHAPTER II

EXAMINATION OF PREVIOUS WORK

THE CONSTITUTION OF MIND IN GENERAL

BEFORE proceeding further it will be well to review, in the light of the foregoing chapter, the work of previous investigators so far as it relates to our subject. As the latter is concerned with perceiving and thinking, i.e. with 'cognitive' ability, rather than with feeling and willing, we shall confine our attention to those researches which deal with this aspect of mind. The investigations to be considered fall into three classes, namely those which seek to enlarge our knowledge of the constitution of mind in general; those whose object is to discover the particular type of mind required by the professional engineer; and those which aim at disclosing the nature of the special mental processes, 'abilities' or 'aptitudes' required for certain specified engineering occupations. Let us consider these in turn.

N. Carey. Within the first of these classes is Dr. N. Carey's interesting study of the mental processes of school children.[1] The aim of this study was to discover how the various mental processes involved in schoolwork are related to one another; whether, for example, those who excel in the discrimination of differences in the pitch of musical notes also excel in discriminating differences in the rate at which they occur, or to take another example, whether

[1] 'Factors in the Mental Processes of School Children,' *Brit. Jour. of Psych.*, vols. vii and viii.

the child with a good 'colour-sense' had invariably a good memory for colours.

Dr. Carey's results are mentioned here for two reasons. In the first place, they were directly opposed to that view already mentioned which divides mind into various 'faculties', such as a faculty for 'judgment' by means of which all our various judgments are carried out, another for 'memory', a third for 'imagination', and so on. Secondly, that kind of thinking about mechanical objects which forms the subject of the present research appears nowhere among the mental activities of the school children studied by Dr. Carey. This bears out a conclusion to which we come later, that seldom do the subjects taught in the elementary school call for the exercise of this kind of thinking.

C. Burt. This same fact comes to view in the extensive inquiry into the relations between the various school subjects which has been carried out by Professor Burt,[1] for none of these subjects appears to have required thought about mechanisms. Handwork, as we see later, may do so under certain circumstances, but the chief requirement of the handwork included among the school subjects studied by Burt seems to have been manual skill, for it was found to be specially related to drawing and writing, and all three subjects were classified together as a 'manual' group.

Burt points out that children backward in the formal subjects of the curriculum are sometimes found to excel in 'handwork'. This might be accounted for by the manual factor. But it might also be partly due to some special 'mechanical' factor connected with the particular kind of thinking processes involved in the handwork, and which only further analysis of the handwork itself can disclose.

A large number of tests applicable to school children are given by the same author in his important book on

[1] *The Distribution and Relation of Educational Abilities*, L.C.C.

mental and scholastic tests.[1] Among these are to be found none intended to measure a special 'mechanical' ability as such, although in the tests suggested for 'handwork', the testee is required to make models of simple objects, such as houses, stools and wheelbarrows, with wooden blocks and other material, and so needs a certain measure of ingenuity. Mechanical movements, however, do not appear to have been introduced into these objects, and the tests also require such manual skill as may be necessary to put the parts together.

Sex differences were observed with these tests, especially in invention and design, and the performances of defectives were found to differ less from those of normal children than was the case with tests of the school subjects. Indeed, the overlapping in ability which was found to exist between the 'normals' and the 'defectives' was so great as to render misleading any attempt to draw a borderline between these two groups of children. Since experiment has not disclosed any marked sex differences with respect to general intelligence, and we should certainly expect the defectives to do decidedly worse than the normals at a general-intelligence test, the sex differences and 'overlapping' shown by these handwork tests suggest that they call for some special ability (or abilities). This points to the desirability of further research to determine how far such special ability may be referred to the manual side of these tests, and how far to the cognitive processes involved in designing the models.

F. Gaw. A study of the mental qualities measured by fourteen tests of the kind known, somewhat loosely, as 'performance tests', has been made by Miss F. Gaw.[2] To find out what abilities were measured by these, they were compared by correlation coefficients, with customary measures of 'general intelligence', with what the author

[1] *Mental and Scholastic Tests*, L.C.C.

[2] 'A Study of Performance Tests,' *Brit. Jour. of Psych.*, vol. xv, 1925.

refers to as tests of 'mechanical ability', and of 'constructive ability'. The 'mechanical' tests employed by her were Stenquist's Assembling Tests, Series I and III, and Healy's Puzzle Box. In each of the Stenquist tests the subject is required to assemble ten common mechanical objects, such as a bicycle bell, clothes pin, lock, etc. The Puzzle Box 'is a wooden box with a glass top and four holes cut in the sides and bottom. It is fastened by a complicated system of cords and rings slipped over pegs inside the box. The problem is to open the box with the aid of a button-hook which may be inserted in the holes.' The tests were given to a group of elementary school boys, varying in number, according to the test, from 30 to 52, and to a similar group of girls.

While the correlations which Miss Gaw obtained between the 'performance' and the 'mechanical' tests were useful in affording some indication of the extent to which both groups of tests involve the same ability, it is evident that if the mechanical tests are to be used as instruments with which to diagnose the actual qualities tested by the 'performance' tests it is necessary to know what qualities are measured by the mechanical tests themselves.

It appears from this study, and from her remarks elsewhere,[1] that Miss Gaw accepts the view that each of the latter tests involve a special 'mechanical' ability which is independent of general intelligence; that is to say, that there is a common unitary factor running throughout the mechanical tests upon which success at them depends, and which is measured by the scores made at them. Such a view implies at least two things, firstly that these tests measure in common the same ability, and secondly that that ability is 'mechanical' ability.

With regard to the first of these implications, the existence of a unitary ability common to all the mechanical tests and measured by them could only be proved by

[1] Vide 'The Use of Performance Tests and Mechanical Tests in Vocational Guidance,' *Jour. of N.I.I.P.*, vol. i, 1923.

elaborate correlational statistics which neither Miss Gaw, nor anybody else, has yet supplied. We show, later, that even the relatively high inter-correlations between the tests which were found by Stenquist cannot be taken as conclusive evidence for the existence of a single unitary factor running throughout them. Moreover, in our own experiments these high inter-correlations were not obtained. Regarding the second of these implications—the nature of the 'ability' measured by the mechanical tests—this must be sought in a subjective analysis of the tests themselves. Before these can be regarded as tests of 'mechanical ability' such analysis must clearly show what are the mental processes which we may regard as 'mechanical', and that it is these processes rather than other, non-mechanical, ones that determine success at the test. No one has yet done this in respect of the mechanical tests employed by Miss Gaw. Indeed from Miss Gaw's own evidence it is far more clear that other factors of a non-mechanical kind enter into these tests than that they involve mechanical processes. Much closer analysis than has yet been attempted will be necessary before we can see clearly what are the abilities measured by these tests.

J. L. Stenquist. We have now to consider a work which is much more closely related to the subject of our own research than any reviewed so far—that of Professor J. L. Stenquist.[1] In 1919–20 Stenquist gave to several hundred boys in a New York City Public School a series of 'intelligence' tests together with his own mechanical tests. The latter were two assembling tests known as Assembling Series I and II, and two picture tests, referred to as Picture Test I and Picture Test II. Each of the former required the subject to assemble as quickly as possible ten common objects, such as a cupboard catch, clothes pin, etc. Picture Test I consisted of 78 picture-matching problems in which the subject must determine which one of five pictures belongs to one key picture. The pictures treat of general

[1] 'The Case for the Low I.Q.,' *Jour. of Ed. Research*, iv, 1922.

mechanical subjects such as mechanisms, toys, machines and their parts. Picture Test II is similar to I, but involves, in addition, language. It includes sixty questions referring to numbered parts of machines.

From this study Stenquist concludes that there are two kinds of general intelligence—one kind measured by the 'general intelligence' tests, and another measured by the mechanical tests. Since this conclusion is of fundamental importance for vocational guidance in engineering, it will be well to consider the arguments upon which it is based.

Stenquist found that the mechanical tests inter-correlated, 'on an average, between ·6 and ·7', and that 'one test of actual manipulation of objects, such as Series I, correlates about as high with either of the picture tests as it does with a second series of models to assemble'. From this he argues that, 'on the whole, any one of the four tests affords an important indication of a general ability that may for convenience be called general mechanical aptitude—general in the sense that it does not pertain to any special trade, and mechanical, as is more or less obvious from its nature'.

While we should agree with Stenquist to the extent of saying, in the light of their inter-correlations, that the tests involve some common ability (or abilities), we should hesitate to say, on the basis of a mere correlation between each pair of tests coupled with a glance at the tests themselves, what the ability was. Even the brief description of them which Stenquist subsequently gives fails to make this clear—much less is it 'obvious' from their nature. Neither is it evident from these data that the ability measured by the tests is 'general'—even in the sense in which Stenquist here uses it.[1] Moreover, as we show later, the term 'general' may be given a much more definite and fruitful meaning in this connection than it has when used in this sense. It would seem desirable to restrict its use

[1] That is, in the sense of being of 'general importance in everyday life'.

o this more definite meaning, especially if, as Stenquist ubsequently does, we are to compare the 'general ability' ieasured by the mechanical tests with the 'general ability' ieasured by customary intelligence tests.

Having decided on this rather slender basis that his ests measure 'general mechanical aptitude', Stenquist roceeds to examine the correlations between them and a composite score' derived from six well-known tests of general intelligence'. The correlations here were found range from ·23 to ·52, and when the scores at the four iechanical tests were combined the correlation with this telligence score was said to fall to ·21. From the generly low correlation between the two kinds of tests Stenquist gues that 'an individual's position in general intelligence thus shown to be largely independent of his position in eneral Mechanical Ability and Aptitude'.

Before commenting on this argument, attention must e drawn to a mathematical error which occurs in the data 1 which it rests. It is impossible for the correlation etween the 'pool' of the four mechanical tests and general intelligence' to fall below the lowest correlation any one of the mechanical tests constituting that 'pool' ith the same 'general intelligence'. It is therefore fficult to see, from Stenquist's figures, how the correlation etween the sum of the four mechanical tests and 'general telligence' could fall to ·21. Its value, calculated from enquist's coefficients by Spearman's formula for the orrelation of sums or differences (giving equal weights each), is ·42.

Granting, however, that the mechanical tests correlate ss with 'general intelligence' than with each other, we ve yet to ask whether this is sufficient to prove the istence of two independent abilities. Given are (1) ie correlation between different measures of a supposed echanical ability, and (2) correlations between these and supposed measure of 'general intelligence'. What, then, Stenquist's criterion to show that all these correlations

cannot be attributed to one and the same element? There is none formulated by him, and certainly none is involved in (1) being higher than (2), as he seems to think. Moreover, his data are not sufficient to employ the genuine and sole criterion.[1] Still more needful is such an exact and demonstrated criterion when the possible influence of sampling errors has to be estimated. He may be right in his deductions, but certainly he has not proved them.

Stenquist next investigates the validity of his tests by comparing them with criteria in order to determine what it is that is measured by them. The criteria chosen were pupils' ranks at shop courses and at general science, as estimated in each case by the teachers. Here the correlations were found to be high—varying from ·42 to ·90—from which Stenquist rightly argues that 'the mechanical tests may, therefore, be judged from these figures to detect to a marked degree the same qualities in pupils that are considered by the shop and science teachers in judging pupils' relative abilities'.

But when he goes on to ask, 'What is it that causes a pupil to stand out in this type of work? May it not be another type of intelligence that might well be called of general importance?' we can only reply that there is no evidence in these correlation coefficients for such a belief. Unless we are shown either by the correlations between shopwork and general intelligence, or by an analysis of this ability itself (preferably by both), that rank in shopwork does not depend on general intelligence, we have no reason whatever for supposing this to be the case—rather the contrary. Without such evidence the natural assumption is that success at these proposed criteria (shopwork and science) would depend largely on general intelligence and that, consequently, the mechanical tests also (seeing that they correlate well with the criteria), involve this same ability. In brief, until we know what abilities are involved in shopwork and general science these cannot be used as

[1] See p. 107.

criteria with which to diagnose the mechanical tests. To suggest as a result of this comparison that the criteria depend on mechanical ability is to beg the question at issue, and to assume as true what the very criteria were brought forward to prove, namely, that the mechanical tests themselves are valid measures of mechanical ability. Without further knowledge of the abilities involved in shopwork and science, this comparison throws no additional light on the nature of the ability measured by the mechanical tests.

As another way of deciding what the mechanical tests measure, Stenquist turns to 'the very direct one of merely looking at the tests and judging what type of task it is that has been set up'. 'Thus,' he continues, 'we may note at once that they represent an attempt (in all except Picture Test II) to get away from words. They deal with concrete and real things. In the Assembling Tests opportunity is given to work with hands and mind, rather than to perform with pencil only, or to juggle mental abstractions.'

This description does not seem to us to provide indisputable evidence that the tests measure 'mechanical ability'—or even any ability other than general intelligence, for this same description would apply with equal aptness to many so-called 'performance' tests. These have been shown to measure, largely, general intelligence.[1] Even if it be granted, as seems probable, that the 'mechanical' tests involve other abilities besides general intelligence, it still remains to ask what these may be. If we look for them in the above description we are led to suggest that at least one of them may prove to be motor dexterity rather than mechanical ability.

Moreover, despite his earlier assertions, Stenquist him-

[1] See the study by F. Gaw referred to on p. 14; also an unpublished thesis by Dr. McCrae entitled *Some Effects of Social and Educational Opportunities upon Mental Tests* (London Univ. Library).

self is not very sure what his tests measure, for he says, 'Possibly it would be more appropriate to designate these mechanical tests by some other name, for they are mechanical only in a limited sense. On the mental side they call for ability to recognize parts of ordinary mechanical devices, for the ability to make judgments as to the reasons for the particular size, shape, weight and nature of the parts—in short, for the mental ability to think through in some degree the same steps as those employed by the designer of each machine. Manually, they call for the dexterity required to put parts together to form the completed machine or device after it has been decided how they should go. A generous amount of the best kind of thinking is then required to make a high score. It involves accurate perception, reasoning, and judgment applied to each model. In so far, therefore, as these mental processes are of general importance in everyday life, the ability demonstrated in assembling the models perfectly could well be called general intelligence.' In the light of this we may well ask, why indeed call it anything else? Nowhere does his analysis indicate the special 'mechanical' factor which these tests are said to measure.

THE PROFESSIONAL ENGINEER

B. V. Moore. Among the more extensive investigations into the mentality of the professional engineer is that of B. V. Moore.[1] The aim of this investigator was to discover 'methods and means for selecting and placing young engineers in the type of work which they can do best'. The engineers in question were the apprentices at the Westinghouse Electric and Manufacturing Company, and the main problem which Dr. Moore set himself was to differentiate successfully between those best fitted for the work of salesman and those more suited to that of design engineer.

[1] 'Personnel Selection of Graduate Engineers,' *Psych. Rev. Monograph*, No. 138, 1921.

To this end, various lines of research were pursued. The grades which the subjects had previously made at Technical Schools were compared with other criteria, such as estimates of intelligence, with class grades made in the firm's Education Department, with grades made in the shop, and with various ratings on a number of character traits made by the shop foreman. The vocational and avocational interests of several types of engineers employed by the Westinghouse Company were inquired into by means of questionnaires. In addition, psychological tests were given. It is with these, as being most likely to exhibit the presence of innate mental differences, that we are here concerned.

A general-intelligence test, known as Personnel Bureau Test VI—a modified form of the American Army Test—was given to ninety-four graduate engineers classified into four occupational groups, namely, design engineers, general engineers, operating, service and works engineers, and sales engineers.

The average score made by each group followed the order in which they are here named, the design engineers, as a class, doing much better than the sales engineers. There was, however, considerable overlapping in ability as from one group to another, some of the sales engineers making as high a score as the best design engineers.

On this account Moore concluded that a general-intelligence test was not able to distinguish satisfactorily one type of engineer from another, and argued that the difference in intelligence between the sales engineers and the design engineers was a qualitative rather than a quantitative one. He also thought that any of the available intelligence tests would be too easy and too lacking in interest for engineers.

All four groups were small—particularly the design group, which appears to have numbered about six. This renders any comparison between them of doubtful value. But if anything can be concluded, it is surely that the

design engineers, as a class, were of superior intelligence to the sales engineers.

To continue our account, the unsatisfactory result with Bureau Test VI led Dr. Moore to devise a special test for differentiating between 'sales' and 'design' engineers. This consisted of two parts—Part I, intended to measure the kind of mentality needed by a salesman; Part II, that needed by a design engineer. A quarter of Part I was composed of general-information questions; the remainder consisted of 'analogies', 'opposites', 'synonyms', a test in which proverbs had to be paired according to their meaning, and a test in which sentences had to be correctly completed by one of three given words. Part II consisted of a test in which the names of five technical objects (or engineering terms) were presented and the subject required to select the four which possessed the same (unstated) technical property and to underline the one which did not possess this property, a test in which certain technical statements had to be marked true or false, and a test in which the solutions to a number of technical problems were required.

The test was given to 28 design engineers and 59 sales engineers, all of proved ability at their respective tasks. The design engineers secured an average of 109·3 on Part I, and 37 on Part II, whereas the sales engineers scored an average of 87·6 on Part I, and 22·7 on Part II. Moore argued that these results supported his contention that Part I of the test measured the kind of intelligence needed by sales engineers, and Part II that needed by design engineers, because the former did better in Part I as compared with Part II than did the latter. Thus the sales engineers scored approximately four times as many points on Part I as on Part II, while the design engineers scored only three times as many. On the basis of this difference between the scores for the two parts Moore decided to differentiate one type from another. Thus the person who had a wide difference between his two scores

in favour of Part I would be assigned to the sales department, while one who had a relatively smaller difference (though still, perhaps, in favour of Part I) would be placed as a design engineer.

This argument involves several disputable points. In the first place the units at different parts of the scales have not the same values and are therefore not comparable. If, for example, units above point 88 in Part I scale happened to be worth double those below it, and those above point 23 in Part II scale were only half those below it, the design engineers' scores (keeping those of the sales engineers as before) become 130 and 30 for the two parts respectively. Such figures are directly opposed to Moore's conclusions.

Another difficulty lies in the fact that there are two ways of arriving at a difference between the scores for the two parts—either by subtraction or by division. In placing his subjects Dr. Moore assumed that either method was valid—but they lead to contradictory results. Thus to revert again to the average scores, the difference becomes, by subtraction, 72·3 and 64·9 for the 'design' and 'sales' engineers respectively. On these figures the greater superiority of the design engineers (by Moore's criterion) lies in Part I—the part specially devised for sales engineers.

Even if a satisfactory method of measuring them could be devised, these differences would afford no indication of the relative ability of the men at the type of work to which they had been assigned, for a man making low scores in both parts might well have a larger difference between them than one making higher scores in both, but would not on that account be the better man in either. A criterion which thus 'selects' but does not 'grade' is hardly satisfactory, since it may well lead to the overloading of a department with men who, although better suited to enter it than any other, are nevertheless 'weak', and so not necessarily well placed so far as the interest of the organization as a whole is concerned.

Equally unsatisfactory seems the method of grading the sales engineers (after selecting them) by combining both scores, if, as Moore claims, the two parts of the test really measured different abilities, for there is no reason to think that a person with a high (or low) score in one special aptitude is thereby rendered more (or less) efficient in another. Neither is it logical to suppose that for differentiating the men the two parts of the test function as special aptitude tests, while for grading them they may be regarded (and so combined) as a general-intelligence test.

So much for the practical difficulties inherent in the method, but is not the idea itself fundamentally wrong? Surely the criterion is not to be found in the difference between the scores at the two parts but in the actual scores themselves. If two qualitatively different kinds of intelligence existed, and were correctly assigned to the respective groups, we should expect sales engineers to do better than design engineers in Part I, and worse in Part II. In actual fact, the design engineers do better in both parts. If anything can be inferred from this it is that the same kind of intelligence functions in both parts, and that the design engineers, through their superiority in this, were able to make much higher scores in both.

There are still to be explained the relative differences between the two scores at the two parts upon which Dr. Moore places so much importance. This seems best accounted for by the superior technical knowledge of the design engineers whereby they were enabled to place a still greater distance between themselves and the sales engineers in Part II (which required, throughout, this kind of knowledge) than in Part I.

Throughout the research no criterion is put forward for deciding whether the mental differences looked for really exist, the author being always content with a mere comparison between scores or correlation coefficients—without even considering the sampling error which, with the small

groups sometimes used, must have been large.[1] Until these are duly taken into account the data, however interesting in other ways, have actually proved nothing.

While a vast deal of useful information about the subjects' school grades, interests, hobbies and the like, has been collected, little, if any, attention is given to the innate mental qualities upon which these must in part depend. Any sound method of differentiating between the various engineering groups must rest, ultimately, upon a knowledge of these innate factors, and research in this direction should greatly illuminate the important problem which Dr. Moore has courageously tackled in this investigation.

C. R. Mann and E. L. Thorndike. In his book, *A Study of Engineering Education,* Prof. Mann describes some investigations made by Prof. Thorndike to determine the capacities required by the professional engineer. The fifteen tests employed were tests of achievement in English, mathematics, physics, together with Stenquist's Assembling Tests. Each test was said to be 'designed to record the student's relative ability in some one particular activity which was complete in itself', and to differ from the ordinary college examination in its attempt to place as little emphasis as possible on knowledge and as much as possible on the ability it was designed to test.

The tests were given to thirty-four engineering students of Columbia College. The scores at the various tests were 'pooled' and the combined score so obtained was found to correlate with High School Scholarship records, Regent's Examination records, Freshman Year record, Opinion of Classmates and Opinion of Teachers to extents varying from ·62 to ·75. When the records and opinions, together with ratings according to the combined judgment of the Dean and teachers, and according to age, were combined into a single rating for 'general intellect', this rating was found to correlate with the combined test score to the

[1] The sampling error is that which arises through measuring only a limited number, or 'sample', of individuals.

extent of ·84. The same rating gave fairly high correlations with each test taken singly, with the exception of three of the physics tests and the Stenquist test. While, however, both this physics group and the Stenquist test gave low correlations with 'general intellect', they correlated highly (·6) with each other.

Thorndike concludes that everyone of the tests, except the Stenquist test, is symptomatic of 'general intellect', and when combined become symptomatic of it to a high degree. But he does not tell us what he means by 'general intellect'.

He further states that the tests fall into four groups, namely a group which measures, mainly, general intellectual ability; a group (the three physics tests mentioned above) which measures the same abilities as the former group, and, in addition, other (unnamed) abilities which seem likely to be specially prophetic of success at engineering; the Stenquist mechanical test, which has much in common with the former group and much peculiar to itself; and an English group, which has much in common with the first ('general intellect') group and much peculiar to itself.

This grouping, however, is very rough-and-ready. The criterion necessary to determine whether special abilities (i.e. those independent of 'general ability') are involved is not used, neither are Thorndike's data sufficient to permit of its employment.

SPECIFIC OCCUPATIONS

We now come to those inquiries which examine the mental processes needed for more or less specific engineering occupations. Although those are primarily concerned with the analysis of the 'job' rather than of the mind, and are seldom able, for reasons already stated,[1] to enlighten the problems of mental abilities by direct experimental

[1] See p. 9.

evidence, yet in so far as they are concerned with mental operations, and more especially as their conclusions are frequently based on assumptions about the nature of mental abilities, factors, capacities, etc., it is desirable to consider such of them as relate to our present subject.

H. C. Link [1] gave Stenquist's Mechanical Test and a test said to measure 'perception of form' to two groups of men engaged in assembling gun parts. The inter-correlations were found to be ·42 and ·58. Link suggests that these correlations indicate special abilities in the tests. In themselves, however, these figures provide no evidence for supposing the abilities to be 'special' rather than 'general'.

Lipmann and Stolzenberg [2] enumerate various qualities, such as delicacy of touch, form recognition, mental representation of objects (imagery), immediate memory for special order, attention, dexterity, etc., which they consider important for those engaged in the metal industry. Among them is included the ability to understand the construction and functions of machines. These appear to be regarded as special 'faculties' or 'capacities', for each person's grades in all the tests designed to test any one capacity are averaged to give the specified capacity 'index'.

It does not follow, however, that because various attributes are grouped together under the same general name (such as 'form recognition', 'imagery', 'immediate memory', etc.), that those attributes will even correlate, much less function as an unitary 'power' or 'faculty'. There is no evidence whatever for thinking that the various capacities mentioned above exist in this sense.

Moreover, as Muscio has already pointed out,[3] the tests used by these writers for measuring the ability to under-

[1] H. C. Link, *Employment Psychology*, Macmillan, 1919.

[2] *Methoden zur Auslese hochwertiger Facharbeiter der Metallindustrie*, Barth, Leipzig, 1920.

[3] In *Reports of the Industrial Fatigue Research Board*, No. 12, Vocational Guidance, p. 27.

stand simple machines test knowledge of elementary mechanical principles rather than innate ability.

M. Tagg, by observing and introspecting on the operations carried out by workers engaged in various engineering trades, analyses the cognitive requirements of the engineering worker into—(1) General intelligence, and (2) Specific abilities, innate or acquired, which may, or may not, be correlated with general intelligence.[1] The specific abilities postulated are, 'perception of space and form', 'memory of form', 'size,' etc., 'motor ability', 'attention', 'creative imagination' (also referred to as 'creative faculty') and 'accuracy of detail'. Of them, he says, 'Some abilities, such as, say, visual discrimination, are probably constant through the normal life of the individual in so far as its purely physical components remain constant, but there are other innate abilities, e.g. creative imagination, which are capable of great development.'

Reference is made in the next chapter to the need of clearly defining the terms commonly employed in this sphere of work. The desirability of so doing is illustrated here where some confusion appears to exist in the use of the terms 'general' and 'specific'. In accordance with the 'general factor theory' (whence these terms have sprung), the scores at any given performance may be divided into two parts, one determined by the 'general' factor, and the other by the 'specific' factor. The latter is called 'specific' because it is peculiar or 'specific' to the performance in question and quite independent of the 'general' factor which, as its name implies, occurs to varying extents in all mental performances. We can therefore hardly speak of 'specific abilities which may, or may not, be correlated with general intelligence'.

The criticism of the qualities postulated by Lipmann and Stolzenberg applies also to the 'specific abilities' put forward here. As has been pointed out already, there

[1] 'The "Make Up" of the Engineering Worker,' *Jour. of N.I.I.P.*, p. 313.

is no experimental evidence that 'creative imagination', 'memory of form, size, etc.', 'accuracy of detail', and the other 'abilities' mentioned by Tagg exist as such. The available evidence is to the contrary.[1] Experiment has shown that while several psychological processes may seem sufficiently alike to be grouped together under one name, such as 'memory of form and size', it by no means follows that they will function as a unitary special ability which can be measured. Such assumptions are of more than theoretical interest, for they might easily lead to the giving of vocational advice on the assumption that the 'creative imagination' of a Shakespeare is the same as that of a Stephenson or an Arkwright.

Moreover, as is frequently the case with this type of analysis, the results are not expressed in terms of ultimate mental processes, and are consequently of little assistance in the work of constructing tests. This is seen in the case under review, where the tests subsequently chosen for various engineering occupations were selected not on account of their being tests for the 'specific' abilities postulated, but for their resemblance to the actual trade operation it was proposed to measure. This kind of analysis seems to have fulfilled little practical purpose.

CONCLUSIONS

It is evident that few investigations into the mentality of the engineer have been pursued from the standpoint put forward in the last chapter as being of fundamental importance for scientific vocational guidance: that is, with the object of discovering what are the special aptitudes or innate abilities required by various branches of engineering. Among these few, unfounded assumptions concerning the constitution of mind have been the rule rather than the exception, and much has frequently been lost through failing to separate 'acquired' factors from innate. Moreover, such data as have been obtained have seldom been

[1] See the work of Carey, Philpott and McCrae.

examined in the light of satisfactory mathematical criteria. On this account, little scientific evidence for the special abilities or capacities which have been said (or assumed) to exist has been forthcoming. More frequently, investigators have been concerned to discover good tests for special occupations, and here the work of subjective analysis had been seldom supported by experiment. Throughout, with rare exceptions, the need for defining explicitly the questions at issue, for giving precise meaning to the terms employed, and for using those terms consistently and unequivocally, is made manifest. These matters are considered in the next chapter.

CHAPTER III

THE PROBLEM

THE PRESENT POSITION

FREQUENT *Assertions.* We have seen that it has been frequently asserted that persons differ in respect to a certain ability which has been variously called 'mechanical ability', 'mechanical aptitude', or 'mechanical intelligence', and that attempts—notably that of Prof. J. L. Stenquist—have already been made to measure this ability. Nor have psychologists been alone in this, for engineers have themselves used the term 'mechanical sense' to denote a marked ability at understanding mechanisms, at repairing machines and dealing generally with things mechanical. The 'mechanical sense' has been described by a well-known physicist who writes: 'Lastly, students differ in another respect, which is not quite so obvious, but is, I believe myself, of equal importance, i.e. in their possession of what I may call the mechanical sense. This is a real sense, as much as is the artistic or the musical sense. It does not always go with mathematical ability, nor even usually so. It is not worth while trying to define it exactly, but I know that a student who possesses it knows exactly what the lecturer means when he is trying to describe the working of a piece of apparatus when others cannot understand what he means.'

Little Evidence. Notwithstanding these assertions, belief in a special 'mechanical ability' or 'mechanical sense' has rested upon empirical observation, without clear proof

of its existence, or insight into its psychological nature.

Justification of Further Research. Nevertheless, a clear understanding of this so-called 'mechanical ability' promises to be of such value in vocational guidance and selection and in certain branches of educational practice, that it was considered worth while to embark on extensive research into its existence and nature, involving the collection and submission to definite criteria of the necessary experimental data, and a subjective analysis of the relevant psychological processes.

PSYCHOLOGICAL CONSIDERATIONS

General Problem of Mental Measurement. The nature of our problem will be more evident if, before attempting to formulate it, we consider certain matters related to it. Let us first take the case where we wish to predict, by the aid of mental tests, a person's suitability for a given vocation. The latter will usually involve the carrying out of many different performances. Most of these performances will involve complex activities, themselves capable of resolution into a number of more elementary ones. Moreover, account must be taken of the future and often unparticularized demands of the vocation as well as of its more immediate and obvious requirements. It is clear that the number of activities involved will usually be so great as to render their individual measurement out of the question. We are therefore compelled either to resign the task altogether, or to be content with a restricted number of measurements. In the latter case we are at once faced with the question as to whether it is possible to infer anything about the rest from the measurements of the few? In other words, can we, and if so under what circumstances, select from these performances some which will afford a truly representative sample of the rest? The reply will depend on the functional relationship which may be found to exist between them. It is evident that before we can embark on any programme of mental measure-

ment for vocational guidance we must have some knowledge of this functional relationship—we must know how the abilities demanded by the vocation are related to the processes involved in our tests.

Functional Relationship between Performances

What, then, is this relationship? Three typical views are to be found. These may be called 'anarchical', 'monarchical', and 'oligarchical' views respectively.[1]

1. *Anarchical View.* According to this view a person's ability in any given performance depends on a complex of independent mental elements. These are held to function in various combinations which differ, in nature and number, according to the performance much as the combinations of musical notes differ according to the chord struck. On this theory two entirely dissimilar performances would depend on two entirely different groups of elementary operations, while performances would be similar (and correlate) only to the extent to which they depended on the same elementary factors.

2. *Monarchical View.* This view holds that all the various performances a person may carry out are dominated by a unitary mental element which is common to all and determines, at least in part, his success at every one. Unlike the other views, then, this regards no performances, however dissimilar, as entirely independent.

3. *Oligarchical View.* Finally it has been frequently assumed that a person's various performances may be grouped in such a way that all falling within the same group are in some way interdependent (or even identical, as when the various acts of observing are said to be the expression of a single 'observation power'), while those falling within different groups are entirely independent. Such theories vary in detail according to the way in which the grouping is assumed to occur. They are implied in

[1] Terms suggested by C. Spearman, *The Abilities of Man: their Nature and Measurement*, Macmillan, 1927.

such doctrines as those of mental 'faculties', 'types', 'levels', etc.

4. *Modifications.* While the above theories represent broadly the three distinctive ways in which various performances have been held to be related, modifications of these are at least thinkable. Of these the more important would consist in combining the monarchical view with either of the other two. Its combination with the anarchical view would give one in which every performance would be regarded as dependent on a unitary mental element common to all performances together with one (or more) independent element peculiar to the performance itself, and only to such other performances as may also involve it. By combining the monarchical and oligarchical views we should get one in which the various 'faculties' or 'capacities' would be no longer regarded as entirely independent, but related by a unitary element common to them all.

Bearing on Mental Tests. Such theories bear directly on the use of mental tests. If the anarchical view were correct almost every performance would need testing separately—and then preferably by a direct sample of the performance itself. Vocational guidance could hardly hope to go beyond tests for specific and well-defined occupations. If the relations between performances were 'oligarchical', vocational guidance would best proceed by discovering and devising tests for the various 'faculties' or 'powers'. A knowledge of the faculties required in a given vocation, together with their measurement in a given individual, would then afford some indication of the latter's suitability for that vocation. But on the monarchical view, the plan of procedure must be to discover means of measuring the common element in individuals and of determining the extent to which the various performances (or vocations) severally depend on this factor. Such data would afford an important (though not, of course, complete) indication of a person's likelihood of success in any given

vocation. This inquiry would have to be coupled with a careful investigation into the other factors upon which success at various performances may depend, and into the relationships which may be found to exist between them.

The Theory of ' g '. The criterion needed for determining which of the three types of theory is the correct one has been established by Prof. C. Spearman. To this logically demonstrated criterion Spearman has submitted a vast amount of data collected from a variety of sources, and has thereby shown that all the available evidence favours a combination of the monarchical and anarchical views which he has called the 'Theory of *g*'. Briefly, this theory states that a person's ability in any given mental performance is determined partly by a factor which is common to all his other mental performances (in the sense that these also depend partly on the same factor) and partly by a factor (or factors) peculiar to the performance itself. The former is known as the ' general common factor ', or simply *g*, while the latter is referred to as the specific factor. All performances, however, do not depend to equal extents upon *g*—in some, a person's success may depend almost entirely upon the functioning of this common factor; in others, but very little. Similarly as regards the 'specific' factor—some performances involve a large 'specific' element, in others this factor may be almost absent, success then depending almost wholly on *g*. The extents to which the 'general' and 'specific' factors function are thus held to vary independently from one performance to another. Expressing the theory in another way, we may say that a person's score at a mental test may always be divided into two parts, one of which is a measure of the extent to which the score depends on '*g*', and the other a measure of the extent of its dependence on the 'specific' factor. It must be added that although the general factor functions as a unitary whole the facts of the theory do not prevent its being regarded as composed of more elementary

constituents, neither are the 'specific' factors necessarily ultimate, or even wholly psychological. By them are meant, rather, all the conditions affecting the score other than the general factor.

Consequences of '*g*'

Let us now consider some of the consequences arising from this theory.

1. *Meaning of 'General Intelligence'.* Since the term 'general intelligence' has been used throughout the literature of vocational psychology, and no study of a 'special' ability can well be made without some reference to it, we may best start by considering the light thrown by the above theory on the meaning to be attached to this term.

With the nature of the psychological processes underlying intelligence the theory is not concerned, for this can be discovered only by an analysis of 'intelligence' itself.[1] But to the question, 'In what sense may "intelligence" be called general?' the theory gives a definite reply, for it clearly finds one general factor, and one only. Consequently any mental ability (such as 'general intelligence') which is said to function 'generally' must needs be identified with this general factor. If (as is sometimes the case) it be argued that the word 'general' is intended in some other sense than this, the obvious reply seems to be that any other sense must be too vague and indefinite to be serviceable, if it be not altogether meaningless. If, on the other hand, it be argued that by 'intelligence' is meant something other than the general factor (and the meanings assigned to it have, indeed, been almost as numerous as the writers upon it), the answer is that whatever may be intended by this other sort of intelligence, there is no evidence to show that it functions generally, nor, indeed, to show how it functions at all. It would

[1] Such analysis has been carried out by Prof. C. Spearman, in *The Nature of 'Intelligence', and the Principles of 'Cognition'.* Macmillan, 1923.

seem then that 'general intelligence', if it is to mean anything, must be identified with the 'general common factor'.

2. *Measurement of Intelligence.* Moreover, the common practice of measuring intelligence by averaging the scores at a variety of mental tests, is only justified by the presence of a factor common to them all; if each of these tests involved different factors the average score would not be a measure of any.

3. *Analysis of Tests.* It is commonly supposed that a test which correlates highly with a given vocational performance may, on that account, be regarded as a special test for that performance, i.e. as a test which measures some particular 'ability' needed in the vocation in question. But this correlation may be due largely to the general factor. This renders it necessary to know the extent to which such may be the case, before we can regard the test as one of 'special' ability.

Similar remarks apply to the practice of measuring various activities involved in a given occupation and then combining these scores into a single one to denote the testee's (so called) special ability for that occupation. Such a composite score is more likely to measure general ability, or *g*, for the effects of different special abilities involved (if any) will tend to cancel each other when the scores are added together.

It is clear that in accordance with the *g* theory the special ability which a test may measure cannot be estimated without some reference to the general ability on which it must also, to a greater or less extent, depend.

4. *Analysis of 'Ability'.* An analogous case occurs when considering the nature of a particular 'ability'. It is often taken for granted that a person's superiority at a given kind of work is due to some special ability for that work. While this may be so, it does not follow immediately from the mere fact of his superiority, for this would be due to some extent (varying of course with the nature of the work) to the general factor—*g*. No analysis of

'ability' can be considered complete which does not allow for this fact.

The view which regards general intelligence as a number of different kinds of intelligence, or as the average of a number of particular abilities, may be similarly criticized. On the theory of g it becomes necessary to inquire how far the so-called special kinds of intelligence involve a factor common to them all, and how far they depend on factors peculiar to each of the kinds of 'intelligence' in question.

5. *'Specific' and 'Group' Factors.* We have seen that by the theory of g any test score may be divided into two parts, namely $g + s$, where g is the part dependent on the 'general common factor', and s is that dependent on the factor 'specific' to the test in question. Let us now suppose that we have a group of tests, such as X, Y, Z. Each of their scores may be written $(g + x)$, $(g + y)$ and $(g + z)$ respectively, where g represents that part of the score in test X which is dependent on the general factor (its value being the same for all tests), and x represents the remainder; and similarly for tests Y and Z. Now the extent to which each pair of these tests would be expected to correlate on account of the common g factor may be calculated.[1] If this is done, and the degree of correlation is then found to be wholly accounted for by this factor, we must suppose that those parts of the scores represented by x, y and z are uncorrelated, i.e. that the factors upon which those parts depend are 'specific' to their respective tasks. But if the inter-correlations indicate that in addition to the correlation due to g there is further correlation due to a factor (f), common to x, y and z, then we may rewrite these parts of the score as $(f + p)$, $(f + q)$ and $(f + r)$, where f is that part of x dependent on the factor f while p is the rest of x, and similarly for q and r. The three scores then become $(g + f + p)$, $(g + f + q)$, and $(g + f + r)$. Unlike the universal g, the influence of f is restricted to a particular group of

[1] For method, see Appendix, p. 205.

tests. On this account f has been called a 'group' factor. Thus, if we include the possibility of group factors, a test score may be thought of as consisting of n parts, namely one part dependent on the universal factor, g, $n-2$ parts each dependent on a factor common to a restricted group of tests (group factors), and one part dependent on a factor (or factors) peculiar to the test itself (the specific factor or unanalysed remainder). Hitherto, however, little evidence of any important group factors has been found, so that for most tests $f = 0$ and $n = 2$.

Use of Terms

1. *'Special' Ability.* We may now give clearer meaning to the term 'special ability'. Often this is intended to mean the whole concrete performance. For example, 'mathematical ability' is commonly called a 'special ability'. But 'mathematical ability' is the ability to do mathematical work, and as such may be expected to involve the general factor. It would therefore make for greater clearness and accuracy to limit the denotation of the term 'special ability' to that part of the performance which is found to depend on a group (or specific) factor. We should then speak of the special ability or factor involved in mathematics rather than of a 'special mathematical ability'. Conversely, when a group of performances are found to depend partly on a group factor they may be said to involve a 'special' ability.

2. *'Ability' and 'Aptitude'.* Frequently the term 'ability' is used as if it were synonymous with 'aptitude'. Thus we have the terms 'practical ability' and 'mechanical ability'—used to imply special innate mental qualities. But since the term 'ability' must obviously extend its meaning to cover any kind of performance whatever, it would seem desirable to continue its employment in this wide sense, and to use the term 'aptitude' when only the innate character of the 'ability' is intended. Employing the terms in this way, we should say that a person actually able

to carry out 'mechanical' work has 'mechanical ability', while one who has the appropriate innate mental constitution for acquiring this ability (whether he has actually done so or not) may be said to possess 'mechanical aptitude'.

3. *Mental Process.* We shall refer to any mental act as a mental process. This may be either elementary or complex. In the latter case it may be analysed into more elementary processes. By 'unitary' processes we shall mean those which cannot be analysed into more elementary ones. Our knowledge of mental processes will naturally depend to a large extent on introspection.

4. *Factor.* The existence of a 'factor' is sought in the relation between correlation coefficients rather than in introspection. We have already had occasion to use this term. Perhaps we may now generalize, and define a 'factor' as part of the constant cause of correlation between two or more performances. Unlike a mental process, a factor is not necessarily a psychological entity—its interpretation will depend on the analysis of the performance in which it is found to occur.

AIM OF THE PRESENT RESEARCH

The chief questions which arise in connection with our problem may now be formulated as follows:

The Existence of 'Mechanical' Aptitude. We have seen that no satisfactory proof has yet been offered that the ability to deal mentally with mechanisms involves a special aptitude. Consequently before attempting to describe, or measure, such an aptitude, our first problem must be to inquire into its very existence. To do so we must first determine whether ability for one kind of 'mechanical' work (the psychological nature of which will itself call for examination) goes with ability for other kinds, i.e. whether a measurable 'ability' for this sort of work exists. Should this prove to be the case, our next step must be to inquire into the factors involved, and especially how far this ability depends on the general factor, and how far on specific, or group, factors peculiar to the work itself.

The Nature of 'Mechanical' Aptitude. So much for the quantitative aspect of our study—but this alone, however fruitful in showing the existence of factors, can tell us little about their psychological nature, for this is the work of subjective analysis. Consequently, alongside of the measurement of ability at the various tests must go a qualitative study of the nature of the mental activities which they involve. Here, by means of introspection, we shall aim at resolving these activities into their unit processes. By so doing we may hope to gain insight into the nature of any special 'mechanical' aptitude, or other factors, which our measurements may disclose.

The Measurement of 'Mechanical' Aptitude. If our inquiry is to bear practical fruit it is not enough to show that a special ability exists, we must also know how to measure it. Consequently we shall examine our data for any indication as to how we may measure, with sufficient accuracy, any special ability that may be revealed to us, keeping in mind the facts relating to the general problem of mental measurement discussed above.

Significance of Results. Finally, it is important to inquire into the psychological significance of the results arrived at. How do these bear on psychological theory,[1] on vocational guidance and on educational practice? Here we shall be concerned with such questions as whether the ability in question, as Stenquist affirms, is rightly regarded as another kind of intelligence, or whether it is, as Thorndike suggests of some of his tests, specially indicative of success at engineering. This latter question is only part of the larger one concerning its whole vocational scope. Equally important are many questions bearing on current practices in education which a clearer understanding of 'mechanical ability' may hope to throw light on. These considerations are reserved for the latter part of our inquiry.

[1] Especially with regard to the above described views concerning the way the mind is held to function.

CHAPTER IV

GENERAL PLAN OF THE RESEARCH

DEVELOPMENT OF NEW TESTS

EXAMINATION of Existing Tests. It seemed desirable to start with material closest to hand, namely, existing mental tests. The most promising of these—the ingenious assembling tests devised by Stenquist—were given to adults and to children of both sexes. The results, however, did not prove satisfactory for our present purpose, for the tests showed little correlation with each other, and were found to involve a certain degree of digital strength and skill; moreover, the subjects were frequently familiar with the objects to be assembled. It therefore became necessary to devise new tests, which would call for those mental processes which seemed to form a characteristic element in the operations commonly attributed to 'mechanical ability'.

Desirable Test Qualities

In devising these tests we were guided by the following considerations:

(1) *Saturation.* In order to simplify the subsequent work of interpreting results, and to ensure the maximum 'saturation' with mechanical operations, any obviously non-mechanical operations (such as those involved in motor dexterity) should be avoided.

(2) *Unity.* In an inquiry into the relationship between mental abilities, or qualities, it is desirable that each test

should involve one measurable quality only. To this end the various sub-tests (or parts) of a test should call forth as far as possible the same sort of ability. This property of a test might be called its 'unity'. Its presence will be shown by the correlation between the sub-tests.

(3) *Reliability* (*or Constancy*). A measuring instrument is not satisfactory unless it gives constant measures when applied to the same thing under the same circumstances. Similarly, a test would not prove a reliable measuring instrument unless its various 'forms' yield concordant measures. Some indication of the extent to which this may be the case is afforded by the correlation between the two halves of a test (known as its 'reliability coefficient'). By increasing the number of elements in a test (and so increasing our 'sample' of the performance to be measured) and by decreasing the units of performance employed as a basis for marking (so that smaller differences in ability may become apparent), we tend to increase its reliability.

(4) *Duplicability*. For practical purposes it is important that attempts at coaching for the tests should be frustrated. To this end it should be possible to prepare many 'forms' of the same sort of test. Consequently the material of the test should be of such a kind as to render this possible.

(5) *Objectivity*. The difficulty of measuring ability at any complex performance by purely objective criteria is well known, and accounts for the fact that tests involving drawing, composition, handwork, construction, and similar complex activities are often marked by reference to a subjectively determined scale. Owing to the unreliability of a subjective estimate we preferred to make our tests and marking entirely objective in character by assigning a definite mark to every point at which the subject had an opportunity of making a response. Where subsequent experiment showed that some points in the test were more difficult than others the marks for the former were slightly raised. Where correct alternative solutions were given

they were, of course, accepted, and so marked that the maximum score was the same irrespective of the method adopted.

(6) *To Measure 'Aptitude' rather than 'Achievement'.* Since we wish to investigate innate mental constitution, and to obtain tests which would measure a person's latent 'power' to profit by appropriate training rather than a concrete ability acquired as a result of training, the tests should, as far as possible, be independent of scholastic attainments and of special knowledge or training (including, of course, special environmental influences). They should, in other words, measure innate ability or 'aptitude' rather than achievement.

(7) *To Measure 'Power' rather than 'Speed'.* Without suggesting that these are independent, we wished to measure 'power' rather than mere speed. Consequently we included questions of varying difficulty, and compensated for certain disadvantages that this might bring by making successive variations in difficulty small, and arranging the more difficult questions in such a way that points could be scored at parts of these by subjects who might be unable to answer the whole question. To do this we aimed at selecting material which would lend itself to the construction of problems of varying difficulty, and arranging these problems so that while all subjects would be able to do some, none would do all.

Construction of New Tests. We sought to incorporate these features in a variety of new tests, so constructed as to involve, in a high degree, those elements which we had found to characterize the various operations commonly attributed to a 'mechanical ability'. These tests were 'tried out' and revised in the light of experience until they gave sufficiently reliable results to warrant their use on a larger scale.

THE SUBJECTS

(1) *Untrained Subjects—Commerce Students.* When the tests had reached a suitable form they were given to several

groups of students of both sexes attending a Senior Commercial Institute, and varying from 14 years to adult age. These were attending courses in English, mathematics, one (and in some cases two) foreign language, theory and practice of commerce, and, in some cases, shorthand and typewriting. None had received technical training in engineering subjects. All were destined for commercial work. In these respects they differed entirely from the R.A.F. subjects described below.

For instructional purposes they were divided into the following groups according to their educational attainments and age:

Group I, forty ex-service men, most of whom were over twenty years of age. On leaving the army these men had taken advantage of a Government grant to improve their qualifications, with a view to taking up commercial work.

Group II, a class of ten boys and sixteen girls, of average age fifteen years eight months. These subjects were in the second year of a two years' commercial course which was begun nominally at the age of fourteen.

Group III, a class of twelve boys and ten girls of average age fourteen years six months, in the first year of the above-mentioned commercial course.

In order to examine separately the data relating to each sex, the boys of Groups II and III were put together to form a Group A, and the girls similarly to form a Group B.

(2) *Elementary School Boys.* The tests were subsequently given to the three upper classes of a London elementary boys' school, numbering altogether 114 subjects whose ages ranged from ten years to fourteen years three months. None of these had received special training in mechanics or any other technical subject involving a knowledge of mechanisms. They were encouraged, however, to make things at home, and some emphasis was placed on handwork in school. In this the boys were encouraged to develop their own ideas, and a few who

showed special aptitude were allowed to devote extra time to woodwork at a bench which had been specially installed for this purpose. Many of the elder boys attended a manual training centre where they were taught woodwork on one afternoon each week. In a school of this type the more intelligent of the pupils above eleven years of age are 'creamed' off to attend Secondary or Central schools. Beyond this, these subjects were unselected and untrained as regards mechanical work. They were tested in the following groups:

Group IV, the sixth and top class of the school, consisting of 36 pupils, of average age 12 years 11 months.

Group V, the fifth class, containing 37 pupils of average age 12 years 5 months.

Group VI, the fourth class, numbering 41 pupils of average age 11 years 5 months.

(3) *Trained Subjects—R.A.F. Mechanics.* Our third set of subjects consisted of 228 students taking the Passing Out Examination of a large R.A.F. Technical School, after a three years' course, to qualify as mechanics in various trades in the R.A.F. These students enter the school as Boy Mechanics between the ages of 15 and 16 years (in exceptional cases the age may be extended to 17 years), and receive a three years' apprenticeship training in one of a number of trades together with a course of education including English, citizenship, practical mathematics, applied mathematics, mechanical drawing, general science, and physical training. The boys are not allowed to complete the course unless they pass the intermediate tests and otherwise show satisfactory progress during the period of training. Among the more important trades into which the successful candidates pass out are those of carpenter, pattern maker, coppersmith, draughtsman, various kinds of fitter, instrument maker, wireless operator mechanic and electrician. This group, then, had been both 'selected' and 'trained' for this kind of work. It is referred to in our results as Group VII.

THE DATA COLLECTED

(1) *From the Commerce Students.* After the specially devised tests had been tried-out on a limited number of adults and children they were given, as group tests, to the commerce students. It was not found possible to give all of the nine tests employed to every group. This hardly mattered since our main object, in this early testing, was to see whether the tests could be suitably used as group tests, and whether they were likely to yield the kind of data required to throw light on our problem. In addition to these special tests some of the subjects were able to take one of the customary forms of 'intelligence' test.[1]

(2) *From the Elementary School Boys.* The results obtained with the commerce students proved to be of sufficient promise and importance to warrant the further collection of data. Consequently, after slight modifications had been introduced in the light of these results, the tests were given to the elementary school boys. In addition, these pupils' grades at their last three school examinations, based in each case on all twelve subjects of the curriculum, were supplied by the head-master. In the case of those pupils who attended the manual training centre, two estimates of 'ingenuity' as shown (1) in woodwork, and (2) in technical drawing, were obtained from the manual training master. The aim of the research was explained to the master who kindly undertook to give these estimates, and he was asked to base the latter as far as possible on the originality and ingenuity displayed by the pupils rather than on manual skill and care in executing the work. At the same time the estimates can hardly be expected to be entirely free from these influences. It was hoped, originally, to obtain similar estimates of 'ingenuity' from the class teachers, but the teachers of the fourth and fifth classes felt that the pupils' work in school did not provide sufficient opportunity for observing this trait. In

[1] The actual tests and other measures employed in the research are described in detail in the following chapter

the sixth (and top) class the pupils had been in the habit of showing their teacher the various objects which they had been encouraged to make at home, and greater opportunities of doing handwork in school were provided. Consequently the teacher of this class was able to supply two estimates of ingenuity, one based on the handicraft carried out at home, the other on the handwork done at school. Although both estimates aimed at measuring the same sort of ability, it is possible that, being derived from different sources, different factors may have operated in each case.[1] For this reason we have kept them apart in our data.

(3) *From the R.A.F. Mechanics.* Subsequently, we were able to give two of the tests to our last batch of subjects—the candidates at the Passing Out Examination of the Royal Air Force School. These also took a 'Mental Efficiency Test' devised by the Education Department of the Air Ministry, and an intelligence test devised by Professor Spearman. The mental efficiency test consisted of two parts which have been kept distinct in our data, for the first of these resembled certain kinds of intelligence tests while the second seemed akin to our own tests. We were also able to obtain the subjects' positions at the Passing Out Examination, which consisted of (1) a comprehensive written examination in the subjects (mainly technical) of the school curriculum, and (2) a practical and theoretical test in trade knowledge and ability. These, together with the tests, are described in detail in the next chapter.

TREATMENT OF DATA

Testing the Tests. Our first step was to inquire whether the measurements provided by the tests could be relied on. How far, for example, did the scores yield genuine measures of the sort of activity involved, and how

[1] For example, we should expect interest and home environment to play a larger part in home handicraft than in school handwork.

far, on the contrary, were they affected by disturbing influences? Information on this point is given by the correlation between those tests (or parts of a test) which purport to measure the same activity, for measurements of the same thing should, of course, agree within the limits of experimental error. Where complex psychological activities are concerned perfect agreement cannot be expected. In this case the correlations serve the important purpose of informing us of the extent to which our measurements must be repeated and in some way 'pooled', in order to yield a sufficiently reliable measure. The extensive data obtained from the commerce students and the elementary school boys were employed to investigate this question of reliability. With a view to the further improvement of the tests by eliminating those parts which showed little correlation with the rest, we have determined the correlation between each pair of sub-tests, in the case of the elementary school groups.[1]

Examining for Factors. The next part of our research is concerned with discovering what is measured by our various tests and estimates. How far, for example, do they all depend on the same kind of mental ability, and how far on independent abilities? To what extent does ability at the 'mechanical' tests go with ability for school work? Is there any evidence for a special ability which might appropriately be called 'mechanical' aptitude? This inquiry into the factors involved has been effected by calculating the coefficients of correlation between the various parts of our data and examining these in the light of Spearman's criterion for a single common factor.

Measuring the Factors. Our results disclosed the presence of a special 'mechanical' factor. Consequently our next step was to inquire how far success was due to this factor, and how far to the general factor (g). To this end, coefficients showing the extent to which the tests in ques-

[1] It will be seen later that each of the tests employed was constituted of some half-dozen sub-tests.

tion correlate with each of these factors were calculated. These coefficients in turn were used to work out the method of measuring the specific factor—or special ability—in the case of any individual.

ANALYSIS OF TESTS

While the quantitative work outlined above was able to indicate, objectively, the factors involved in our data, it could throw little light on their psychological nature. For this purpose it was necessary to make a qualitative study of the mental activity itself. The tests were therefore submitted to a subjective analysis, based mainly on the introspections of trained psychologists, and carried out in the light of Professor Spearman's principles of cognition. The method adopted here, and the results arrived at, are dealt with in a separate chapter.

CHAPTER V

DESCRIPTION OF TESTS[1]

SERIES I.—TAKEN BY COMMERCE STUDENTS

FOR the sake of clearness it will be well to describe our tests in the same serial order as they were given. Those used in Series II and III are not essentially different from the tests of Series I, but constitute slight modifications of them. The following tests were taken by our commerce students.

'Mechanical Models'

This kind of test employs a series of mechanical models. These were so devised that the subject could only see the first and last link in the series of mechanical events which occurred when the model was worked (by hand). He was required to indicate by a simple sketch (with the addition of such words as he thought necessary) how the observed movements were brought about. Each model was made large enough to be clearly visible to a group of forty children seated in an ordinary classroom. The time allowed the subject in which to work out his answer varied from 3 minutes for the simpler models to 10 minutes for the more difficult ones. Words such as 'pivot', 'slot', 'joint', which the subject might wish to use in describing his methods, were explained beforehand, and the solution of the first model was worked, on the blackboard, as an example. It was impressed upon the subjects to make

[1] Information concerning the tests here described may be obtained from the author.

their drawings clear, and to put in all necessary parts, but marks would be given for ideas and not for ability to draw, and that it did not matter whether they drew their answer from the back or from the front point of view.

The explanation accompanying the exhibition of the first model is necessarily somewhat lengthy, but when once the subjects have grasped what is required of them the experimenter has only to exhibit the model and to point out the essential features to be observed about it. Some examples, with diagrams, must suffice to indicate the kind of concrete models used.

Example. After suitable introductory remarks have been made, a large copy of the model illustrated in Fig. 1 is held up before the group. The experimenter slowly pushes handle A up with one finger, remarking, 'Notice carefully that when this handle is pushed up the other one also moves up, so that both handles move at the same time, also when this is pushed down (illustrating) the other handle comes down. Notice, too, that the model will work from either handle (illustrating by moving handle B up and down), and in any position (illustrating by working the model on its side, and upside down). Now make a simple sketch to show how you think the model is made. First put in the square (C D E F) and the two handles. Then put in the parts which are necessary to make the model work.' One solution is shown in Fig. 1A.

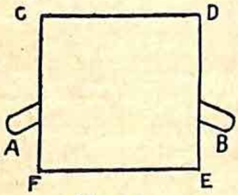


Fig. 1.

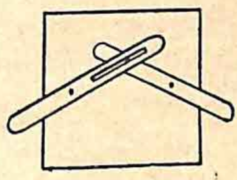


Fig. 1A.—Answer.

Sixteen models of varying difficulty were prepared for this first series and were grouped into tests as follows :—

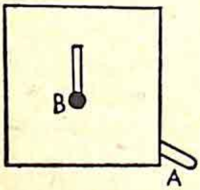
Test M_1

Test M_1 consisted of the following 5 models:

Model 1—as above example.

Model 2:

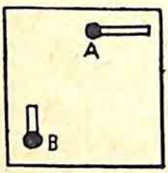
Points to observe: When handle A is moved upwards,



button B also moves upwards in the slot; when A moves down again, B moves down. Model works in any position.

Model 3:

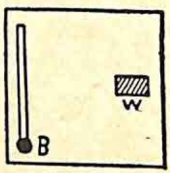
Points to observe: When A is pushed to the right, B travels up its slot; when A is pushed back again (to the



left) B travels down. Model works in any position.

Model 4:

Points to observe: With B in its present position, window (aperture) W is closed by a shutter behind it; as B is pushed up the slot, W opens and remains so until B reaches

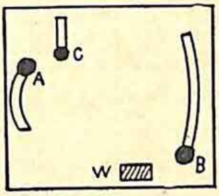


the top of its slot, when W again closes. As B travels down its slot W opens and remains so until B reaches the bottom of the slot, when W again closes. When B is at

the bottom or top, W is open; for all other positions of B, W is shut. Model works in any position.

Model 5:

Points to observe: In the present position of buttons A, B and C, the window is closed. When B is pushed up along its curved slot, both A and C travel along their slots



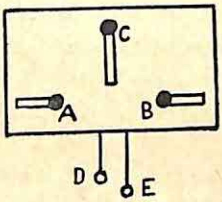
and W opens. The movements of A, C and W are reversed when B is pushed down again. Model works in any position.

Test M_2

Test M_2 consisted of the following three models:

Model 6:

Points to observe: When one string (D) is pulled, C travels down its slot, while A and B move apart (along

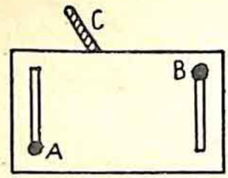


their slots); when E is pulled the reverse movement occurs. Model works in any position.

Model 7:

Points to observe: A and B are buttons which work in slots. When handle C is pushed to the right B travels down, and A up, their respective slots, their movements

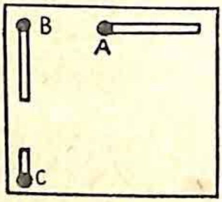
occurring simultaneously. If, when A and B have reached the other extremities of their slots, C is released, the



buttons (A and B) travel back to their original positions (as drawn) of their own accord. Moving C to the left has no effect on the buttons. The model works in any position.

Model 8 :

Points to observe : The model is ready to work when A, B and C occupy the positions shown. When A is passed along the slot to the right, B and C travel along to the



other ends of their slots. When A is pushed back to its first position nothing happens to B or C,—they must be pushed back into their original positions if the model is to 'work' again. The model works in any position.

Tests M_3 and M_4 consisted of another 5 models and 3 models respectively, and were similar in principle to those already described.

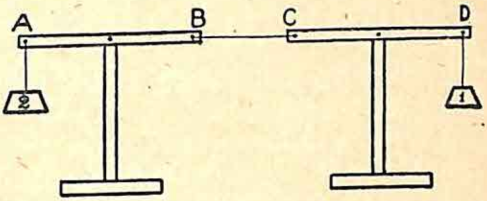
'Mechanical Explanation'

In this kind of test the subject is presented with a paper containing several mechanical diagrams each of which is accompanied by a written description of it. He is required to answer a set of questions about each diagram which involve the explanation of the way various parts of the depicted mechanism work.

Test E_1. (35 mins.)

No marks of any kind to be made on this paper.

1. A B and C D are two rods which balance at the ends of firm upright supports as shown in the diagrams. B and C are connected by a wire exactly as shown.



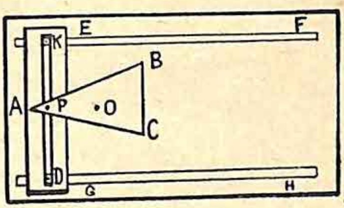
(*a*) If a 2-pound weight is hung at A and a 1-pound at D, what would happen?

(*b*) If the 2-pound weight were transferred from A to B, what would happen?

(*c*) If B were fastened to D by the wire, instead of to C, the rods and weights remaining exactly as in the diagram, what would happen?

(*d*) If B remained fastened to D and the 2-pound weight was transferred to B, what would happen?

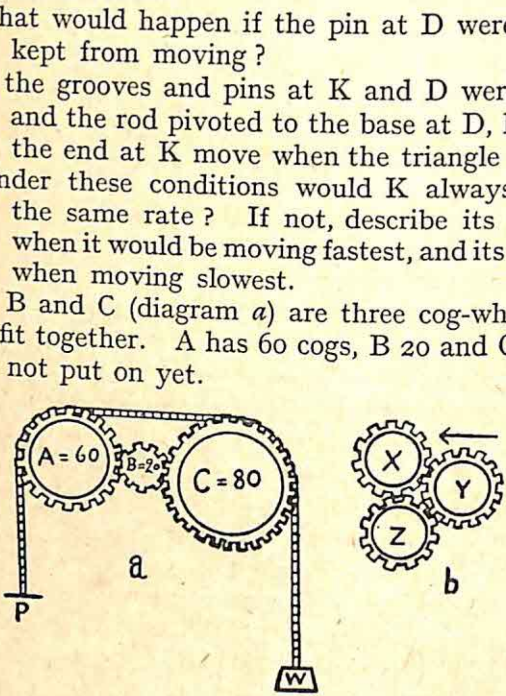
2. A B C is a triangular piece of metal turning round on the pivot O in a clockwise direction. D K is a wide rod with a slot cut in it. P is a pin fixed firmly to A B C and passing downwards through this slot. E F



and G H are long narrow slots cut in the base of the model. K and D are pins fixed firmly to the slotted rod D K and passing downwards through the slots E F and G H respectively. You may assume the model works.

(*a*) When A B C revolves, which point moves quickest and which slowest ?
(*b*) Can you name the path along which A travels ?
(*c*) How does K D move ?
(*d*) Does K D move at the same rate throughout its journey ; if not, briefly describe its kind of movement, saying when it is moving slowest, and when fastest.
(*e*) What would happen if the pin at D were suddenly kept from moving ?
(*f*) If the grooves and pins at K and D were removed and the rod pivoted to the base at D, how would the end at K move when the triangle revolved ?
(*g*) Under these conditions would K always move at the same rate ? If not, describe its position(s) when it would be moving fastest, and its position(s) when moving slowest.

3. A, B and C (diagram *a*) are three cog-wheels which exactly fit together. A has 60 cogs, B 20 and C 80. The chain is not put on yet.



(*a*) If A turns clockwise, in which direction will C turn ?
(*b*) Which will turn round slowest and which quickest ?
(*c*) If, without changing the speed of A, you wished to double the speed of C, how would you alter the size of A ? (Give as accurate an answer as possible.)

(*d*) If the speed and size of A were unchanged, how would doubling the size of B affect the speed of C ?

(*e*) If a chain having links is passed over the wheels, as shown, say accurately what will happen to W when P is pulled down one foot.

(*f*) Which, if either, will travel quicker, P or W ?

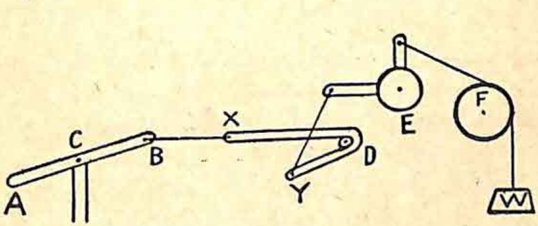
(*g*) If C were made the same size as A, would this change alter the effect on W when P is pulled ? If so, say exactly how.

(*h*) If B were made the same size as A (C remaining its original size of 80 cogs), how would this change affect (if at all) the working of W when P is pulled ?

(*i*) If C were taken away so that W hangs straight from B, how would the change affect the result of pulling P (if at all) ?

(*j*) X, Y and Z (diagram *b*) are three equal-sized cog-wheels fitted together, all touching each other as shown. When X is pushed in the direction shown by the arrow, what happens to Z ?

4. A B is a rod pivoted at C; X D Y is a bent rod pivoted at D; E is a piece of metal pivoted at its centre; separate pieces of wire connect B to X, Y to E, and the



other arm of E to the weight W, after passing over the pulley-wheel F. The various pivots are held firmly in position by suitable supports.

(*a*) If A is released from its present position, would it rise or fall ?

(*b*) When A is pushed downwards, what happens to W ?

(*c*) When A is raised, what happens to Y ?

(*d*) When A is raised, what happens to W ?

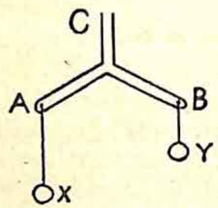
(*e*) If the wire passed straight from the arm of Y to the pulley F, which way would you move A in order to lower W ?

(*f*) If, instead of having the wire B X, the arm X were lengthened and pivoted to B, what would happen if A were pressed upwards ?

(*g*) If all the parts were held in their present positions, then B Y joined by wire and B X cut, also X joined to E and the wire from E to Y cut, what would happen when the parts were released ?

Test E_2. (35 mins.)

1. A B is an L-shaped rod fixed rigidly to an upright rod C. From A and B the weights X and Y are hung. If C were rapidly turned (but kept in its upright position)

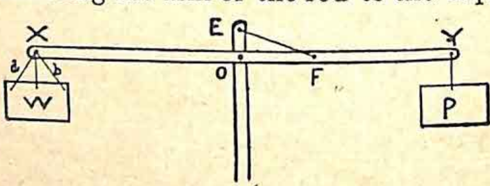


(*a*) Say exactly how X would travel.

(*b*) How would the distance X Y change ?

(*c*) Which would move faster, X or Y, or is there no difference ?

2. X Y is a rod pivoted at O to a support. E F is a string connecting one arm of the rod to the support. W



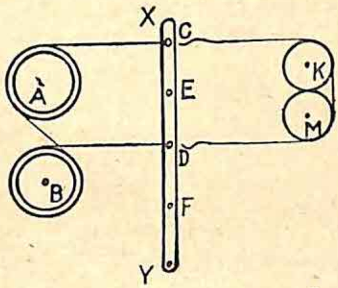
is a weight supported by three strings and just balances P.

(*a*) If *a* and *b* were cut, how would it affect the balance between W and P ?

(*b*) If W were doubled, how would it affect P ?

(*c*) If P were doubled, what would happen to W ?

3. X Y is a straight piece of wood. A string tied at C passes over wheel A in an anti-clockwise direction, then



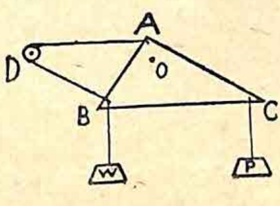
round B in a clockwise direction as shown. It is then pulled tight and tied to D.

(*a*) If X Y works on a pivot at E, say exactly what will happen to A and B if Y is pushed to the left.

(*b*) If the pivot is moved from E to F, what will happen to A and B if Y is pushed as before ?

(*c*) If X Y were taken away and the string passed over the wheels K and M instead of being tied to X Y, what would happen to A and B when K was turned clockwise ? (K and M are fitted together exactly as shown.)

4. A B C is a triangular piece of metal, pivoted in an upright position at O. D is a pulley wheel over which a



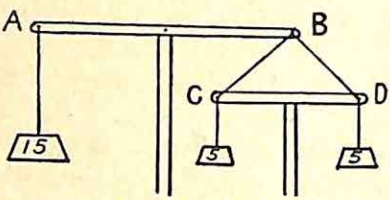
single piece of elastic cord stretches from B to A. Weights W and P are hung from B and C.

(*a*) If the whole remains at rest in the position shown, which arm of the elastic is pulled more, D A or D B, or is there no difference?

(*b*) Say, by looking at the diagram, which is heavier, W or P?

(*c*) If D were moved farther from A horizontally, would B rise or fall?

5. A B and C D are two rods pivoted at their centres to upright supports. Five-pound weights are hung at C and D,



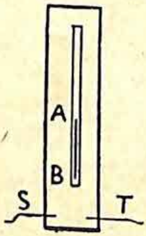
C and D are then fastened to B by strings exactly as shown.

(*a*) If 15 pounds is then hung at A, what, if anything, will happen to D?

(*b*) If B D is then cut, what will happen to C?

(*c*) If the weight at A is then changed to 2 pounds, what will happen to B?

6. A B is a rod which slides in the groove shown. When the string S is pulled B rises to the top of the groove and



returns to the bottom when T is pulled.

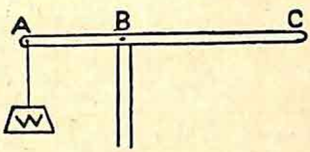
Draw a simple diagram showing how this is done.

'MECHANICAL EXPLANATION AND COMPLETION'

Test EC. (35 mins.)

This consisted of 8 sub-tests. Six were of the 'explanation' type. In the remaining two the diagrams were incomplete, the problem being to complete the diagram so as to show how some given mechanical arrangement could be brought about.

1. A C is a rod balancing on a pivot at B. W is a weight



hanging from A. A B measures one foot. B C measures two feet.

(*a*) If C is pushed downward through a circular distance of 1 foot, say exactly what will happen to A.

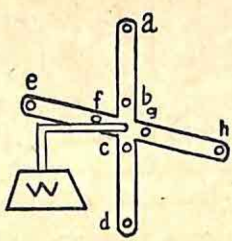
(*b*) Will W change its distance from the ground by more or less than, or the same as, A's distance changed?

2. The wheels of cycle A are larger in circumference than those of cycle B. Both cycles are similar in every other part.

(*a*) On which cycle would you have to press harder to pedal 10 miles per hour along a level road? Give reasons if you can.

(*b*) If the cranks of a cycle were made longer, would you have to press harder or not so hard in consequence?

3. The diagram shows an iron bracket fixed to the wall

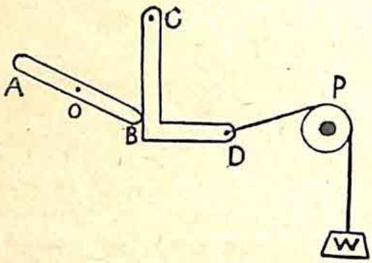


by the holes at *a*, *b*, *c*, *d*, *e*, *f*, *g*, and *h*, and supporting the heavy weight *w*.

(*a*) If you had only two screws with which to fix the bracket, where would you put them in order to fix the bracket most strongly?

(*b*) If you had only one screw, where would you place it?

4. A B is a straight rod pivoted at O. C D is an L-shaped rod pivoted at C. W is a weight supported by a

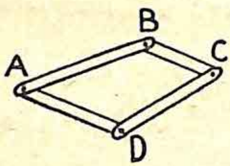


string fastened at D and passing over a pulley wheel as shown.

(*a*) If A is gradually pulled downwards, say exactly what D would do.

(*b*) Say exactly what W would do.

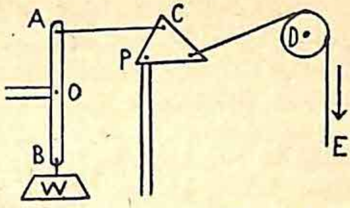
5. A B C D are four strips of wood hinged together. Draw a diagram to show how you would fix this frame



rigid by nailing straight strips of wood to it and using the least possible number of strips.

6. A B is a rod pivoted at O to a support. C is a triangular piece of metal pivoted at P to a support. A heavy weight hangs from B. A C is joined by a string and a string

from C passes over the wheel D, as shown. If its end E is pulled in the direction shown by the arrow,

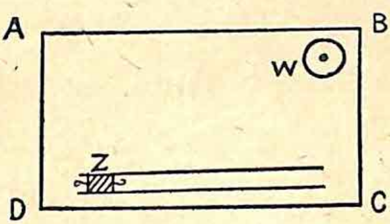


(*a*) Say what will happen to C, and

(*b*) What will happen to W?

7. Show on a diagram which part of a cart-wheel moves quickest at any given instant while the cart travels along. Explain why.

8. A B C D is a table-top. Z is a trolley running on rails. When the wheel W is turned clockwise Z moves



to the right. When W is released Z automatically runs back.

Draw a diagram to show any simple arrangement which will do this.

'MECHANICAL DIAGRAMS'

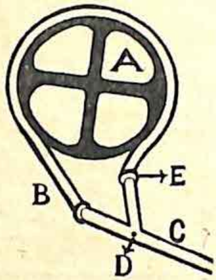
Test D

For this test six large diagrams were prepared. The first two represented actual objects [1] (a brake band and an automatic tipping scale), while the remaining four represented various mechanically connected items, such as

[1] It is unlikely that any of the subjects taking this test would have met with these objects.

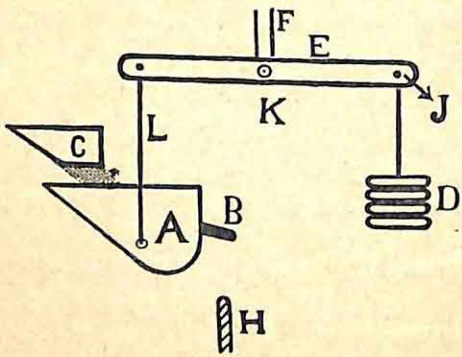
rods and wheels, which although working together constituted no existing object. Each item was clearly lettered. The subjects were required to describe, by referring to these letters, how the mechanism worked. With the commerce students the diagram was simply exhibited and the subjects were allowed to write their descriptions as they thought best. With the younger elementary school groups it was found more reliable to point to, and name, the various parts of the diagram, taking care to give no hint as to how they moved when working, and then to ask questions about the working of these. The diagrams and questions were as follows:

Diagram 1.



(*a*) What happens when C is pushed upwards?
(*b*) What is D for?

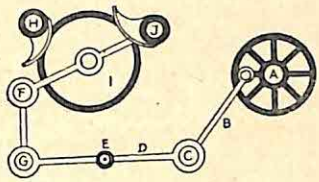
Diagram 2.



(*a*) Explain what would happen if the tap C were turned on and left.

(*b*) What is H for ?

Diagram 3.



(*a*) What happens to I if A is turned clockwise ?

(*b*) If A's direction of turning were reversed, would it affect I's movement ? If so, how ?

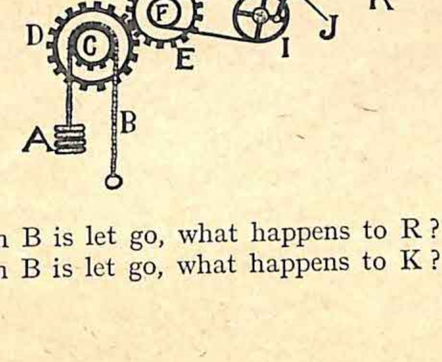
(*c*) If E were removed, would it affect the working of the machine ? If so, how ?

(*d*) What is J for ?

(*e*) Why is J this shape ?

(*f*) What is H for ?

Diagram 4.

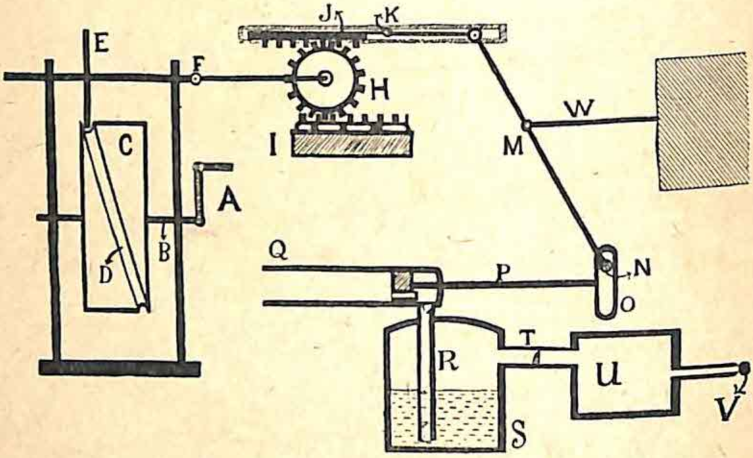


(*a*) When B is let go, what happens to R ?

(*b*) When B is let go, what happens to K ?

(*c*) When I is turned, what happens to M ?
(*d*) When P moves up and down, what happens to R ?

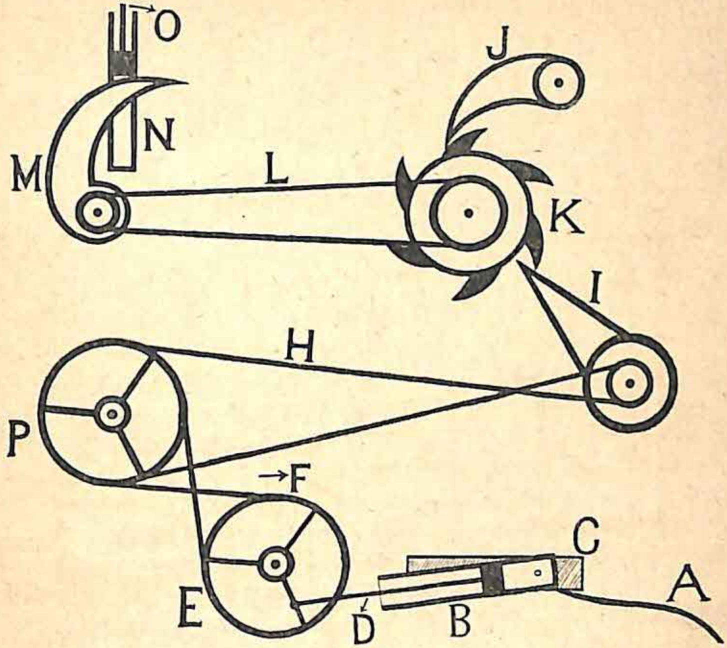
Diagram 5.



(*a*) What is D for ?
(*b*) What is I for ?
(*c*) When A is turned, what happens to E ?
(*d*) When A is turned, what happens to P ?
(*e*) What part, if any, would stop working if W were removed ?

Diagram 6.

(*a*) If steam is passed through A, what happens to O ?
(*b*) What is J for ?
(*c*) Which way does M move ? (Show by drawing an arrow.)
(*d*) Which way does I turn ?
(*e*) Say exactly how K moves.
(*f*) Say exactly how O moves.

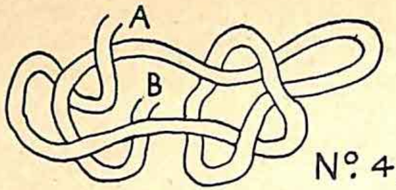


' KNOTS '

Test K

On each of 20 cards large enough to be seen by the group was drawn, in outline, a rope having various twists and turns in it. The cards were presented in turn with the instruction :

' A and B are the ends of a piece of rope lying on a table. If A and B were picked up vertically from the table and pulled apart, how many knots, if any, would be tied in the rope ? ' The making of a single knot was demonstrated practically. As this test proved to have no special value as a ' mechanical ' test, it was not used in subsequent work, and we give here an example only of the diagrams used :



No. 4.

'INTELLIGENCE'

Test G

In addition to the above specially devised tests it was found possible to give to Group II certain of the tests employed as part of the customary 'battery' of intelligence tests. These were given merely for purposes of comparison with the other tests and were not intended to measure, in any complete sense, 'intelligence', or *g*. The tests employed were those known as 'opposites', 'completion' and 'mixed sentences'. In the first of these the subject was required to write against each of a series of words one of opposite meaning; in the second, to complete a series of sentences by supplying suitable missing words; and in the third, to place in correct order the words of a disarranged sentence. Test G is the combined score at the three tests.

SERIES II.—TAKEN BY ELEMENTARY SCHOOL BOYS

'MECHANICAL MODELS'

Tests M_5, M_6, M_7

For this series of experiments eight additional models of the kind employed in Series I were constructed, making altogether twenty-four. They were originally divided into 3 groups of eight each, constituting tests M_5, M_6 and M_7. One of the models in M_5, however, was found to be too difficult for these subjects and was consequently omitted, leaving only seven in this test. Each test included models of varying difficulty—from quite simple to rather complex

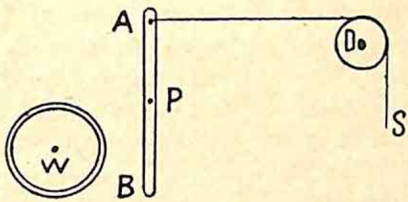
mechanisms. Apart from the greater number of models introduced, and a consequent re-grouping of them, these tests were similar to those already described on pages 46–49.

'Mechanical Explanation'

Test E_3. (35 mins.)

Five sub-tests of the 'explanation' type, three being modifications of those used in Series I :

1. W is a wheel fixed to an upright wall so as to turn. A B is a rod fixed to the same wall by a pivot P so as to



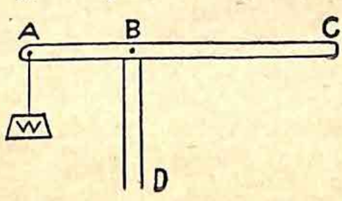
turn round on it like the arm of a windmill. A string is tied to A and passes over a pulley wheel (a small wheel with a grooved rim) as shown at D.

(*a*) What happens when the string at S is pulled ?

(*b*) What change could you make in the way of fixing A B if you wanted the model to work with more force when S is pulled ?

2. A C is a rod fixed to the support B D so as to turn on a pivot at B like the beam of a pair of scales. W is a weight hanging from A.

(*a*) If the rod A C balances, is the part B C heavier, not so heavy, or equal in weight to W ?



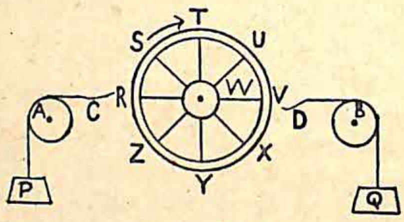
(*b*) If C is pushed six inches nearer to the ground, will A rise more than, less than, or the same distance?

(*c*) If you wanted W to travel further from B, would you push C up or down from the present position?

(*d*) As C is pushed down, would it trace out in the air a straight line or a curve?

(*e*) If C were pushed down from its present position until W was raised three inches higher (measured from the ground), would A have to pass through more, less, or the same distance (3 inches) measured exactly along the path A would travel?

3. W is a large wheel fixed to an upright wall. On each side are pulley wheels, A and B, also fixed to the same wall. P and Q are weights. Strings from these pass upwards over the pulley wheels. The loose ends of these



strings have not yet been fastened to the wheel but are shown at C and D.

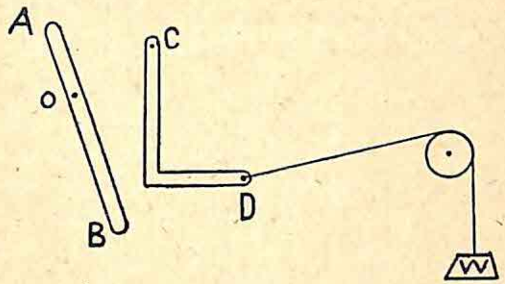
(*a*) To which letter on the rim of the wheel would you fix C, and to which would you fix D, so that when W is turned for a short distance in the direction of the arrow both weights rise equally?

(*b*) To which letter would you fix P so that it first rises and then falls when W is turned as before?

(*c*) Where on the rim would you fix them so that both weights rise, but P rises more than Q when W is turned?

4. A B is a straight rod fixed to an upright wall so as to turn on a pivot at O like an arm of a windmill. C D is an L-shaped rod fixed to the wall so as to turn on a pivot

C. The pulley wheel is fastened to the wall as shown. A string is fastened to D, passes over the pulley and holds the weight W. The whole remains at rest in the position shown.



(*a*) If A were pulled downwards until it could go no farther, would C D move? If so, describe exactly the path D would trace out in the air.

(*b*) Under the same circumstances describe how W would move (if at all).

(*c*) If W grew heavier and heavier and C D is left untouched, will C D alter its position? If so, describe exactly its new position (draw a sketch if you wish).

(*d*) If the *upright arm* of C D were made twice as long and the pivot C placed *correspondingly higher* in the wall, the rest remaining the same, how would this change affect the way C D would move when A is pushed down?

5. A B and C D are two rods fixed at their centres to upright supports by pivots so as to turn like a pair of scales. C and D are then fastened to B by strings exactly as shown. Five-pound weights are hung at C and D. What would you expect to happen

(*a*) If 15 pounds were hung at A?

(*b*) If 2 pounds were hung at A?

(*c*) If 15 pounds were hung at A and B D cut?

(*d*) If 2 pounds were hung at A and B D cut?

And

(*e*) If 16 pounds were hung at A, both weights removed from C and D and B D cut, what weights would you hang and where, so as to make A B balance horizontally (as drawn)?

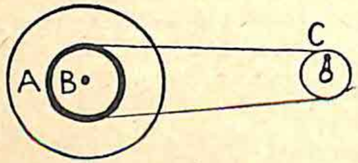
(Same diagram as for Test E_2, Sub-test 5, p. 62.)

'Mechanical Completion'

Test C. (35 mins.)

Six sub-tests of the kind referred to as 'mechanical completion' in Test E C:

1. A is a wheel fixed firmly to a smaller wheel B so that both must turn together. C is another wheel with a handle fixed to it. Wheels B and C have grooved rims



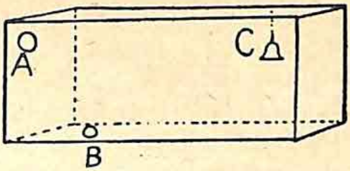
over which a band is passed as shown, so that when C is turned the band turns B and this turns A.

(*a*) What change, if any, would you make in this simple arrangement, so that when C is turned one way A turns the *opposite* way?

(*b*) Suppose you wished A to turn at the same rate as C (so that A turns once every time C turns), what would you have to take care to do when making this model?

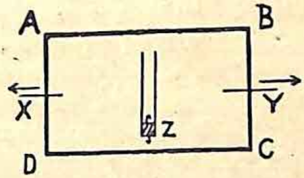
(*c*) What change could you make in the model so as to increase A's speed when C is turned?

2. The diagram represents a narrow box having holes in its front side at A and B. Suppose you wished to fix up a simple arrangement inside, so that when a marble was pushed into the hole at A it hit the bell at C and then



came out of the box at B. Draw a simple sketch to explain how you would make this arrangement. The shape and position of the box may not be changed.

3. A B C D is a large table-top. Z is a truck which runs on a pair of rails as shown. X and Y are strings. While X is being pulled in the direction shown by arrow, Z

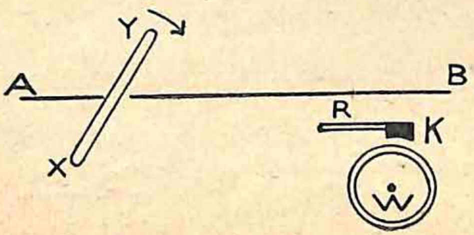


runs to one end of the rails; while Y is being pulled as shown by arrow, Z runs to the other end of the rails.

(*a*) Draw a simple drawing to show how this arrangement is brought about.

(*b*) How would you arrange it so that while one string is pulled the truck runs from one end of the line to the middle and stops, and then while the other string is pulled it continues its journey over the rest of the line?

4. A B represents the floor of a room. X Y is a rod



passing through a hole in the floor. W is a wheel in a room below. K is a block which presses on the wheel when the brake is on. R is a rod fixed to K.

(*a*) Make a simple drawing to show how you would arrange some mechanism so that when Y is pushed in the direction of the arrow the brake K is pressed on to the wheel. Any pivots, rods, etc., which you would use should be shown *plainly*.

(*b*) Can you suggest how you would arrange it so that when Y was released the brake K came off the wheel *automatically*? You may use the same drawing as for (*a*).

(*c*) What special precaution would you have to take when planning this if you wanted the pressure exerted by K to be greater than that put on Y?

5. A B C D is a large flat, level table-top. Z is a small truck which runs on a pair of rails as shown. W is a wheel fixed to the table. (Same diagram as for sub-test 6, omitting P.)

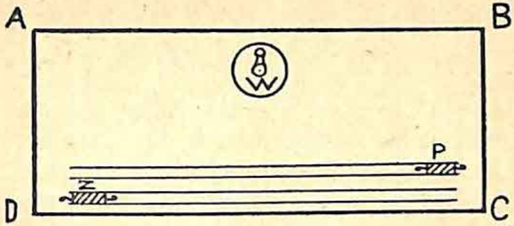
(*a*) Suppose you wanted to fix up an arrangement so that when W was turned by hand the trolley moved from its present position to the other end of the line; make a simple drawing to show how you would do it.

(*b*) Suppose you wanted the trolley, after reaching the end of the line, to run back of its own accord when the wheel was released; make a simple drawing to show how you would fix up a simple arrangement for bringing the trolley back—there must be no mechanism on the trolley itself.

(*c*) Can you suggest a way of increasing the speed of the trolley without turning the wheel W any faster than before?

6. The diagram shows the same table-top as before, but there are now two trucks (P and Z) and lines as shown.

(*a*) Make a simple drawing to show how you would fix up an arrangement so that when the wheel W



was turned each trolley ran to the other end of the line (in opposite directions).

(*b*) Can you show, by a simple drawing, how you would arrange for Z to run twice as quickly as P when W is turned, both running in opposite directions as before?

'MECHANICAL DIAGRAMS'

Test D

The same as Test D in Series I, p. 65.

SERIES III.—TAKEN BY TRAINED MECHANICS

Of our own tests the R.A.F. mechanics were able to take the following:

'MECHANICAL MODELS' (MODIFIED PROCEDURE)

Test M. (30 mins.)

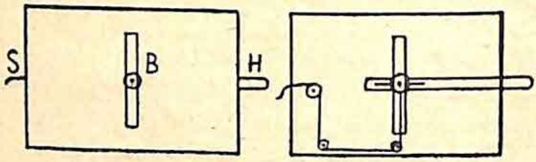
As circumstances made it impossible to present the actual models to this group of subjects, the procedure was modified by presenting instead a drawing of each model, accompanied by a written description of the movements which occurred when the model was worked. As before, the subject was required to show how the described movements were brought about. Each subject was supplied with a paper containing five such diagrams (the first of which was worked as an example) and the following instructions:

'Each of the drawings shows an unfinished sketch of some simple mechanism. Complete each one so as to

indicate how the movements described are brought about. You will be marked on the ideas you display—not on drawing ability. Show essential points clearly. Draw freehand, in pencil. The first is worked as an example.'

Example.

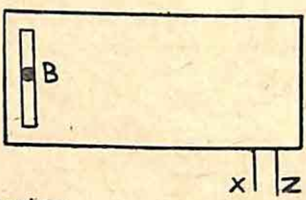
1. B, a button, slides up and down a groove in a flat piece of wood. While H, the end of a rod, is being pushed



Answer.

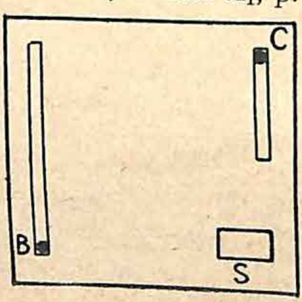
down, the button B moves up. While the string S is pulled, B moves down. Complete the drawing as instructed.

2. The button B moves up the groove when the end of string X is pulled down. It moves down while Z is pulled.



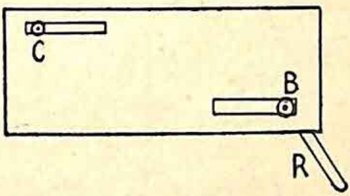
Complete the drawing.

3. The same as Model 4 of Test M_1, p. 54.



4. The buttons B and C work in grooves of different lengths. While B is pushed to the top of its groove C travels to the bottom of its groove automatically, and the shutter S uncovers an aperture beneath it. When B is pushed back again the movements of C and S are reversed. Complete the drawing.

5. R is the end of a rod which, when pushed to the left, causes button B to travel along its groove in the same



direction, and C to travel along its groove in the opposite direction. Complete the drawing.

'Mechanical Explanation'

Test E_3

This was the same as Test E_3 of Series II, p. 71.

Mental Efficiency Examination

The Mental Efficiency Examination consisted of a group of mental tests devised by Colonel I. Curtis, Educational Adviser to the Air Ministry, and given as part of the Passing Out Examinations.[1] It falls into two parts. The following examples illustrate the nature of the tests employed.

Part I.—Test A_1

Three sub-tests constituted this test as follows:

Sub-test A. (3 mins.) Two rows, consisting of figures or other symbols, were presented. In some cases the

[1] See pp. 47 and 49.

figures followed the same order in both rows, in others the order differed. The subject was required to detect these differences in order. The rows increased in length as the test proceeded.

Sub-test B. (10 mins.) Here the subject was presented with a row of numbers or other symbols, which when complete formed a regular series. Some of the numbers, however, were omitted and the subject was required to discover them. The whole test was composed of 11 such series.

Sub-test C. (10 mins.) This was similar to Sub-test B with the exception that every series here consisted entirely of numbers.

Part II.—Test A_2

Sub-test 1. (10 mins.) The subject was required to indicate the position of the creases, and the effect of the cuts which result on folding and cutting a square sheet of paper in a given way. Two such problems constituted the 10 minutes test.

Sub-test 2. (10 mins.) This consisted of two parts. In the first of these the subject was told that a painted 3-inch cube was cut up into 1-inch cubes. He was required to determine, mentally, answers to questions relating to the number of small cubes obtained, the number of saw-cuts necessary, the number of cubes painted on one side, etc. The second part was a variation in which the smaller cubes were re-assembled in stated ways.

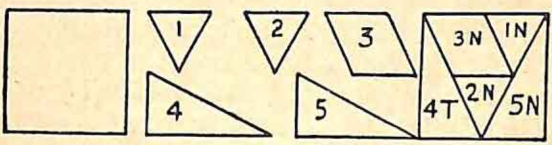
Sub-test 3. (10 mins.) The following is taken from the test, verbatim:

'In a certain type of puzzle, a piece of cardboard or thin wood in the shape of a triangle or other simple figure is divided by straight cuts into a number of separate pieces. These pieces are laid flat on a table, and the problem is to fit them together again to form the original figure. Some of the pieces can be slid directly into place, others have first to be turned over.

'The following diagrams are examples of such puzzles, in which the pieces are to be fitted together to form the figure shown on the left and so arranged that wherever a choice is open those pieces which carry odd numbers occupy the upper and right-hand part of the figure.

'Consider each example in turn; decide first which pieces, if any, must be turned over, and then the position each should occupy, bearing in mind in each case the rule as to the odd numbered pieces. Having done this, draw lines across the corresponding figure in the space marked Test 3 of Part II of your answer sheet, to mark the position of each piece. Then, in each division, write the number of the piece to which it corresponds followed by the letter T, if the piece has been turned over, and N if it has not been so turned.

'Example I has been answered to show you exactly what is required.'



Answer

Sub-test 4. (10 mins.) 'Each of the following diagrams represents a simple mechanism constructed of flat metal plates and bars fastened to a wooden baseboard by screws, about which they can turn or slide. These screws are indicated in the diagrams by small circles containing a cross: for clearness their heads are not shown, but it is to be assumed that in all cases the pieces cannot be lifted from the baseboard. Where two of the metal pieces are connected by a pin-joint, the pin of the joint is indicated by a circular dot.

'The metal plates and bars can be moved by the handles marked X, Y, or Z, and in each example the problem is to determine the character and sequence of the movements necessary to free the central plate, which it will be seen

is prevented from revolving by bolts that slide into notches in its rim.

'Determine these movements for each example and describe them by entering, in the space marked Test 4 of Part II of your answer sheet opposite the words "First movement", "Second movement", and so on, (1) the letter representing the handle moved, and (2) one or other of the words "In", "Out", "Clockwise", "Counter-clockwise", according as the handle is moved towards or away from the centre, or is turned with or against the hands of a watch lying face up on the baseboard.

'Enter only those movements which are essential.

'Be especially careful not to enter any which cannot be made. In the case of the first example, the entries have already been made to show you exactly what is required.' Fig. 2 illustrates the type of diagram employed.

Examination in School Subjects

The following details will indicate the nature of this part of the Passing Out Examination:

Mathematics I. (3 hours.) Part I of this paper consisted of fairly straightforward calculations involving arithmetic and geometry. Of five questions, one required the working out of a solid shape from a plane figure, another a proof of a mechanical movement. Part II contained more difficult problems of a practical kind involving plane and solid mensuration, algebra and elementary trigonometry. One of the five questions involved the working out of relationships between the movements of parts of a mechanism, in another it was necessary to make use of certain relationships between the parts of a plan to calculate its area.

Mathematics II.—Advanced. (3 hours.) This was a more difficult paper in mensuration, algebra, elementary trigonometry and the calculus. Two of the ten questions set needed a knowledge of mechanics, two others involved mechanical movements, and two required the working

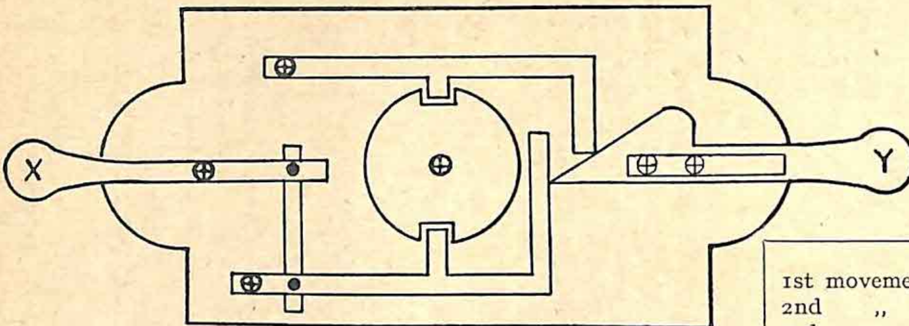


FIG. 2.

	I	
	Handle	Motion
1st movement	X	Clockwise
2nd ,,	Y	In
3rd ,,	Y	Out
4th ,,		
5th ,,		
6th ,,		
7th ,,		

out of space relations between objects from given bearings.

Science I. (3 hours.) This paper contained five problems in applied mechanics and three in heat.

Science II. (3 hours.) This was a more difficult paper than the first science paper, and contained seven problems in applied mechanics and three in heat.

Science.—Questions on Set Tasks. (3 hours.) In this paper the candidates were asked questions on some subject of which they had made a special study, and to solve problems thereon. These subjects were : (1) The Internal Combustion Engine and (2) Properties of Materials of Construction. The questions set in the above papers related, with few exceptions, to machines (in the wide sense) or their parts.

Drawing. (3 hours.) This was an examination in technical drawing in which each group of mechanics took the paper appropriate to his own branch of work. The candidates were required to draw plans, elevations, projections, sections, etc., from given drawings.

English I. (3 hours.) In this paper one hour was devoted to an Essay, the remaining time to questions on English History.

English II. (3 hours.) The first two parts of this paper tested a candidate's ability to write intelligently on matters of general interest, his knowledge of English literature and his general reading ; the remaining three parts dealt with History.

Trade Test

This part of the Passing Out Examination consisted of a practical workshop test in that branch of work for which the student had been trained, a viva voce test in Trade Knowledge, and a written paper in the same subject.

'Intelligence' Test

Finally, this same group of subjects took an 'Intelligence' test devised by Prof. Spearman which occupied 1 hour. This also formed part of the Passing Out Examination.

CHAPTER VI

THE TESTS EXAMINED AS MEASURING INSTRUMENTS

THE MEASUREMENT OF 'RELIABILITY'

'*TESTS' and 'Sub-tests'*. Before proceeding further it will be well to make clear the meaning of the terms 'test' and 'sub-test' as employed in this chapter. In Chapter V a certain piece of work given with the object of measuring a person's ability for that kind of task has been called a test. This has been composed of smaller units of work to which we have given the name 'sub-tests'. It is these tests and sub-tests that are intended here. In our case (and usually) a test is constituted by the whole piece of work carried out by the subject at any one sitting, while sub-tests are, of course, portions of this. Also, within the same test, one sub-test is similar to another as regards the material employed in it, and the kind of activity it is intended to measure, but may differ as regards length and difficulty. For example, the material of each of the sub-tests which form our 'Mechanical Explanation' Test consists of one diagram accompanied by a written description and several questions. The latter will be seen to differ slightly in number and difficulty from one sub-test to another. It is also implied that a person's score at the whole test is based on his scores at each of the constituent sub-tests.

Measures of Reliability. We have seen that before much faith can be placed in a mental test we must be assured that were it (or a similar one purporting to measure the

same trait) repeated, the ratings given on each occasion would closely agree, and we have called this quality its 'reliability'.[1] The best measure of reliability is provided by the correlation between the ratings made at two distinct performances at the test carried out under similar conditions; or where the test does not lend itself to repetition, by the correlation between two similar tests. Where only one test is available a measure of its reliability may be attempted by comparing the ratings made on one half with those made on the other. Further light may sometimes be thrown on the reliability of a test by the correlations between still smaller portions of it, such as our sub-tests, especially as regards the factors making for, or against, this quality. But these various methods of estimating reliability will hardly be expected to agree with one another owing to the following influences.

Influences Affecting Test Scores

(*a*) *Systematic Influences.* The influences which affect the subject's score at a test may be either internal or external. By the former we mean those factors into which the 'work curve' may usually be analysed, and which will therefore tend to be present always. Examples of these are the subject's power to settle down to the task (to 'warm up'), the 'spurts' he may put on from time to time, the practice and the fatigue that may be engendered during the course of the test. By external influences we mean those that are merely attendant on the special time and place of the test and so need not recur on subsequent occasions. Examples of such are the subject's state of health (if abnormal) at the time of doing the test, his mental attitude towards the test, disturbing influences arising from the environment (such as poor lighting), the general state of fatigue and of practice with which the subject approaches the test as opposed to that incurred by the actual carrying out of the test itself. It is clear that in

[1] See p. 44.

giving a series of tests the external influences should be kept as constant and as normal as possible, so that the subject's scores may represent his ability under ordinary conditions. The internal influences are more or less unavoidable, and may even be desirable so far as they occur under normal conditions of work. Nevertheless, it is well that such influences be under observation so that their extents, particularly as regards 'fatigue' and 'practice', may be known.

(*b*) *Random Influences.* The external influences will tend to remain constant through the test, while the internal influences will usually follow the course which they ordinarily take in the work curve. But there are other influences (both external and internal) which exhibit neither kind of regularity. They tend, instead, to be randomly distributed throughout the test. In the sum of a large number of sub-tests such random influences will tend to mutual cancellation. That is to say, the more sub-tests we take (i.e. the more exhaustively we measure the ability in question) the smaller will the total relative effect of such influences tend to become.

Effect on Reliability Coefficients. How, it may be asked, will these influences affect the measure of reliability? To consider first the internal systematic influences; clearly these will be much the same in one test as in another similar test, but will tend to vary from one part to another of the same test. It follows that the reliability coefficient given by the correlation between two complete tests is less likely to be lowered by such influences than is the correlation between parts of the same test. Usually, however, only one test is available and then the correlation between its parts must perforce be employed as a measure of its reliability. When this is so, the effect of the internal systematic influences may be largely eliminated by taking as the measure of reliability the correlation between two halves, each constituted of the sum of alternate small portions of the test, such as our sub-tests. Such elimina-

tion is not, of course, possible in the correlation between single parts of sub-tests. The chief value of these is not so much to measure the reliability of the test as a whole, as to determine the extent to which each sub-test contributes to that reliability. For this purpose the best measure is the average correlation of the sub-test in question with all the other sub-tests.

To turn now to the external systematic influences: it is evident from their nature that these are more likely to change from one complete test to another than from one part of a test to another. Consequently, the changes in such external influences are more likely to lower the reliability correlation coefficient between complete tests than that between portions of the same test. It should be noticed, however, that if the reliability coefficient should be lowered by changes in the external conditions, it does not necessarily follow that the test, in itself, is any the less trustworthy. We may compare such a case with the variations we should get in successive measurements of the length of a rod under changing temperatures. However valuable such measurements may be, they would, taken alone, serve as no criterion for the accuracy of the measuring instrument employed.

To consider, finally, the random influences: we have seen that the more exhaustive our measure becomes, the more completely will these influences tend to cancel one another. Consequently, the reliability coefficient, when based on the more exhaustive (complete) tests, is less likely to be lowered by random influences than when portions of a test are substituted for them.

It should be noted that the foregoing considerations apply only to the methods of measuring 'reliability', and of interpreting such measures—the actual reliability is, of course, quite independent of our method of measuring it.

Summary. Before examining the reliability coefficients which our data have provided, it will be well to summarize the preceding discussion as follows:

(1) For purposes of this discussion a 'test' is a certain amount of work given with the object of measuring a subject's ability at that kind of work, and here, as usually, occupying the subject for one sitting. A sub-test is part of a test such that it carries with it part of the total possible marks for the test. More particularly the terms refer to our own tests and sub-tests, as described in Chapter III.

(2) The reliability of any kind of test is the extent of the agreement between successive measures of a subject's ability as obtained by that kind of test.

(3) Reliability may be measured by the correlation between two similar tests. In certain circumstances the correlation between 'halves' or smaller portions of the test (such as our sub-tests) may be substituted for the correlation between complete tests.

(4) Such substitutes will not be expected to agree with the more perfect measure yielded by the correlation between complete tests on account of—(*a*) systematic influences, which may be either internal or external, and (*b*) random influences.

(5) Of these, the internal systematic influences will have little effect in the correlation between similar tests. Their influence on that between different parts of the same tests will tend to be greater, but may be minimized when correlating 'halves' by composing each half of alternate sub-tests. Changes in the external systematic influences are more likely to affect (by lowering) the correlation between two complete tests than that between portions of the same test. The effects of random influences tend to diminish as our measure of the ability in question becomes more exhaustive. Hence such influences are less likely to affect the correlation between complete tests than that between the less exhaustive 'halves', or sub-tests.

THE RELIABILITY OF INDIVIDUAL TESTS

MECHANICAL MODELS

(*a*) *Correlation between Tests.* As several tests of the

'Mechanical Models' type were employed in the research we were able to measure their reliability by the correlation between complete tests. This will be found in Tables XI–XVI of the Appendix.[1] The average correlations extracted from these tables are given in Table I for the commerce groups, and Table II for the elementary school groups. The reliability is seen to be fairly high, particularly for a test involving a complex activity. The average value of the coefficient in the case of the commerce students is ·75, and for the elementary school boys ·58.

On the surface, the figures suggest that reliability may increase somewhat with the size of the group. To inquire further into this, let us first examine Table I. Here the only comparisons we can make without introducing sex differences are Group I with Group A (both male groups), and Group II with Group III (both mixed groups). In the first case the difference between the reliability coefficients, $\cdot 03 \pm \cdot 06$, is insignificant. In the second case the difference, $\cdot 24 \pm \cdot 08$, being thrice its probable error, is suggestive, though hardly large enough to justify a definite conclusion. Turning to the elementary school groups of Table II, we find the difference between the youngest and oldest groups to be $\cdot 23 \pm \cdot 06$. Here the figure, being nearly four times its probable error, provides more definite evidence of a genuine difference in reliability. A similar fall off in reliability is observed in the case of Group V—the class next to the oldest. In the light of the correlations between halves of these same tests, which are examined below, we have suggested that this higher correlation between complete tests in the case of the older school boys may be due to these boys being less susceptible than the

[1] Here, and throughout the research, correlations between complete tests were calculated by the rank method, using the formula

$$\varphi = 1 - \frac{6Sd^2}{n(n^2 - 1)}, \text{ p.e.} = \frac{\cdot 7063(1 - \varphi^2)}{\sqrt{n}}.$$

Correlations between sub-tests were calculated by the 'footrule' method.

younger ones to what we have called external systematic influences.[1]

A further comparison might be attempted between the commerce students and the elementary school groups. Here the question is complicated by the mixing of the sexes in two of the commerce groups, and by the tests taken by these groups being only about half as long as those taken by the elementary school boys. We may, however, make some compensation for the latter fact by pooling the tests into pairs.[2] If we do this in the case of the two male (commerce) groups, the reliability becomes $\cdot 82 \pm \cdot 04$ for the ex-service men of Group I, and $\cdot 87 \pm \cdot 05$ for the boys of Group A. Comparing these with the figure for the oldest elementary school group ($\cdot 75 \pm \cdot 03$), we find that the differences, $\cdot 07 \pm \cdot 05$ and $\cdot 12 \pm \cdot 06$, are not significant. It would seem, then, that age has little influence on the reliability of the 'models' tests after the subjects have reached about thirteen years.

In Group A and B (Table I) we have a means of examining the influence of sex on reliability. It is seen that, so far as our data go, the tests are as reliable with one sex as with the other.

(*b*) *Correlation between 'Halves'*. In order to analyse further the reliability of the 'models' tests, and to obtain a figure comparable with the measure of reliability which we were obliged to employ where only single tests were taken, viz. the correlation between halves of the test, we have calculated the correlation between the halves ('odd' sub-tests *v.* 'even' sub-tests) for each of the 'models' tests taken by the elementary school boys. The figures given in Table III again show the reliability to be quite good, viz. ·71 on an average.

We may now compare the 'models' tests with each other. The most comprehensive values for this purpose are those

[1] See p. 86.

[2] By Spearman's formula for the correlation of sums.

for the whole of the subjects given in the bottom row of the table. These show that one test is about as reliable as another, for the greatest difference occurring is only ·07, with a probable error of ·05. The same fact comes out if we confine our comparison to the individual groups.

The same table enables us to compare the three groups of subjects with one another. Here, although the coefficients are, on the whole, slightly higher for Group IV than for the other groups and so far support Table II, the differences are not significant. This may, at first, seem to contradict the suggestion which arose out of our examination of Table II above, namely that the reliability of the 'models' tests was somewhat higher with the oldest group. The apparent discrepancy is however easily understood in the light of our discussion on the influences affecting test scores. Here we saw that the external systematic influences would tend, if anything, to lower the correlation between whole tests rather than that between halves of a test. It is possible, then, that the above observed difference in the two kinds of coefficients occur only with the younger groups because of their greater susceptibility to influences of this kind. This view seems to accord with what is commonly found in school work.

(c) *Correlation between Sub-tests.* In order to see how far each sub-test contributes to the reliability of the test as a whole, and with a view to further improving the measuring qualities of the tests by eliminating or regrouping sub-tests where the correlation showed this to be desirable, we have calculated the inter-correlation of the various sub-tests constituting each of the 'models' tests. To preserve homogeneity the data for each of the three classes were treated separately and then averaged. The resulting tables IV–VI do not differ appreciably from the class tables whence they are derived. Considering that each sub-test occupies but a few minutes, and constitutes only about one-eighth of the test, the inter-correlations are, as a whole, fairly high. The average inter-correlation

of all the sub-tests of M_5, derived from the whole of our data as given in Table IV, is ·38, while the corresponding figures for tests M_6 and M_7 are ·40 and ·35 respectively. The individual coefficients, with few exceptions, well exceed $4\frac{1}{2}$ times their probable errors. They are considerably higher than we were able to obtain with the assembling type of test, and compare very favourably with similar data relating to many well-known mental tests.[1]

We have seen that the higher the correlation between the parts of a test, the more likely will the test, as a whole, provide a reliable measure of whatever mental quality (or qualities) may run through each of these parts. Tables IV–VI enable us to see the relative extent to which each of the various 'models' sub-tests contribute, in this sense, to the reliability of the whole test. The most comprehensive value for this purpose will be the average correlation of the sub-test with all the others, found in the bottom rows of the tables. It is seen that with the exception of sub-test *e* in Test M_7, there is not a lot to choose between the sub-tests in this respect. The figures range from ·34 to ·43 for M_5, ·30 to ·46 for M_6, and (omitting *e*) from ·30 to ·40 for M_7. In the case of *e* the average correlation with the other sub-tests falls to ·20. This particular model involved several strings running close together, and unless the subject took care to draw them clearly apart in his answer the latter became difficult to interpret—a fact which probably explains the lower average correlation of this sub-test.

Mechanical Explanation

(*a*) *Correlation between Tests.* Two of the mechanical explanation tests (E_1 and E_2) were taken by Groups I and

[1] Compare, for example, the inter-correlations obtained by F. Gaw with whole 'Performance' tests ('A Study of Performance Tests', *Brit. Jour. of Psych.*, xv, pp. 385–6); also the results of C. M. Davey, who found the average inter-correlation of whole oral tests of 'intelligence' to be ·40, and that of pictorial tests ·31 ('A Comparison of Group Verbal and Pictorial Tests of "Intelligence"', *Brit. Jour. of Psych.*, xvii, p. 27).

II of the commerce students. With Group I the correlation between them proved to be $\cdot78 \pm \cdot04$, and with Group II, $\cdot70 \pm \cdot07$. These figures are fairly high as mental tests go. Actually they are slightly lower than the corresponding figures for the 'models' tests (Table I), but the differences are not significant. Thus, in the case of Group I, the difference is $\cdot02 \pm \cdot04$, and for Group II, $\cdot17 \pm \cdot07$.

(*b*) *Correlations between Halves.* The elementary school groups took only one mechanical explanation test (E_3), and consequently the best available indication of its reliability is given by the correlation between its halves, constituted of odd-numbered and even-numbered sub-tests respectively. This was found to be $\cdot48 \pm \cdot10$ with Group IV (the oldest class), $\cdot59 \pm \cdot08$ with Group V, and $\cdot54 \pm \cdot09$ with Group VI (the youngest class), and for the three groups (averaged), $\cdot54 \pm \cdot05$. These figures, well exceeding as they do the standard of $4\frac{1}{2}$ p.e., quite definitely indicate that the two halves of the test measure much in common, and represent a fair standard of reliability for mental tests of this character and length.

In order to compare the figures with corresponding ones for older groups, we have calculated the correlations between the halves of the mechanical explanation tests (E_1 and E_2) taken by the commerce subjects. They are as follows:—Group I (ex-service men), E_1 $\cdot50 \pm \cdot09$, E_2 $\cdot55 \pm \cdot09$. Group II (10 boys, 16 girls, average 15 years 8 months), E_1 $\cdot61 \pm \cdot09$, E_2 $\cdot43 \pm \cdot12$, and Group III, taking E_2 only, $\cdot63 \pm \cdot10$. These differ little from the figures given above for the elementary groups.

(*c*) *Correlation between Sub-tests.* As in the case of the 'model' tests, and for similar reasons, we have calculated the inter-correlations of the various sub-tests of the mechanical explanation test (E_3) taken by the elementary school groups. As before, the most comprehensive figures will be those for the whole 114 subjects found in Table VII. Considering the brevity of each sub-test quite a fair degree

of inter-correlation exists. Of the ten coefficients, eight well exceed $4\frac{1}{2}$ p.e., while the remaining two closely approach this standard. The average inter-correlation (·39) agrees closely with the corresponding figure for the 'model' type of test.

The same table indicates that little difference exists between the average inter-correlation of one sub-test (with all the others) and that of another. Thus, taking as our comparative figures those based on all the subjects, and given in the bottom row of the table, we find the lowest average correlation of any sub-test with all the others is $\cdot 35 \pm \cdot 06$, and the highest, $\cdot 45 \pm \cdot 06$. The difference ·10, barely exceeds its probable error, ·08, and so cannot be regarded as significant.

Mechanical Completion

(*a*) *Correlation between Halves.* In its complete form only one test of the mechanical completion kind (Test C) was employed in the research. The correlation between its halves ('odd' *v.* 'even' sub-tests), taken by the elementary school groups, was as follows :—Group IV, $\cdot 64 \pm \cdot 08$; Group V, $\cdot 81 \pm \cdot 05$; Group VI, $\cdot 59 \pm \cdot 08$; all three groups (averaged) $\cdot 68 \pm \cdot 04$. The last figure does not differ significantly from the corresponding figures for the tests already examined ($\cdot 71 \pm \cdot 02$, for the 'models' tests; $\cdot 54 \pm \cdot 05$, for the mechanical explanation test), and, as in those cases, denotes a fair degree of reliability for this kind of test.

(*b*) *Correlation between Sub-tests.* The inter-correlations of the six sub-tests of the mechanical completion test are given in Table VIII. These again prove to be fairly high for short performances of this sort. All except one exceed $4\frac{1}{2}$ p.e., and the single exception (·28) closely approaches this standard. Each sub-test, then, may be regarded as measuring something in common with each of the others.

It will be seen from the figures given in the bottom row of the table that the average correlation of a sub-test with all the others in the test does not vary much from one sub-test to another.

MECHANICAL DIAGRAMS

(*a*) *Correlation between Halves.* The reliability of the mechanical diagrams test (D), as indicated by the correlation between its halves, proved to be quite good in the case of the two commerce groups. The coefficients were $\cdot 71 \pm \cdot 05$ for Group I, and $\cdot 76 \pm \cdot 06$ for Group II.

This figure was found to fall to ·35 when the test was given to our oldest elementary school group. Consequently the change in procedure mentioned on page 66 was introduced. This consisted in pointing to and naming the parts of the diagram before putting the questions, instead of simply showing the diagram. The correlation between the halves of the test when this new procedure was employed became $\cdot 45 \pm \cdot 10$ with Group IV, $\cdot 54 \pm \cdot 09$ with Group V, and $\cdot 44 \pm \cdot 10$ with Group VI, the average for the three groups together being $\cdot 48 \pm \cdot 06$.

These coefficients clearly indicate that the two halves of the test measure some mental quality (or qualities) in common. They are, however, lower than the corresponding figures for the two commerce groups which we have just examined. The average of these is $\cdot 74 \pm \cdot 04$—a figure which exceeds that for the elementary school groups (·48) by $\cdot 26 \pm \cdot 07$. Taken in relation to its probable error this figure is suggestive of a genuine improvement in reliability with the older groups, but it is hardly large enough to establish this beyond doubt. Seeing that some improvement in reliability occurred with the elementary groups when descriptive names were given to the parts of the diagram, some fall off in reliability with the younger groups would seem to be traceable to the initial task of translating the abstract lines of the diagrams into concrete 'parts'—a task which we should expect the younger

groups to find more difficult—rather than to the subsequent cognitive work involved in answering the questions about these parts. If so, a further improvement might be effected by substituting pictures for the diagrams, especially with younger subjects.

(*b*) *Correlation between Sub-tests.* The inter-correlations between the six sub-tests which constituted the mechanical diagrams tests have been worked out in the case of our second group of commerce subjects, and are given in Table IX. These show that each sub-test measures much in common with the others. In most cases the correlations are high for the type of performance in question, and well exceed $4\frac{1}{2}$ p.e.

The figures in the bottom row of the table, showing the average inter-correlation of each sub-test with the others, do not differ significantly from one another.

Knots

Correlation between Halves. The knots test (K) was first given to the commerce groups. Owing to its low correlation with the other tests it was then dropped. Two methods of scoring were investigated, namely one in which the answers were simply marked right or wrong and one point given for each correct answer, and one in which extra marks were allowed for more difficult questions and marks were deducted for mistakes. The correlation between halves was, if anything, higher when the simpler method of scoring was used—·84 as against ·77—when tried out on Group III. Consequently this method was the one ultimately adopted. The correlation between halves in the case of Group I, using the simpler form of marking, was ·65, with Group II ·71, and Group III ·84.

THE TESTS COMPARED

Higher Reliability of 'Models' Type. We may now compare the reliability of the tests, taking for this purpose the correlation between their halves. The figures are given in Table X. Those for the 'models' tests are somewhat

higher than the others with both commerce and elementary subjects. With the commerce subjects, the correlation between halves of the 'models' tests averages $\cdot 77 \pm \cdot 023$, but falls to $\cdot 56 \pm \cdot 044$ for the mechanical explanation test, the difference being $\cdot 21 \pm \cdot 05$. Corresponding figures for the elementary school groups are $\cdot 71 \pm \cdot 02$ and $\cdot 54 \pm \cdot 05$, with a difference of $\cdot 17 \pm \cdot 054$. These figures are large enough in comparison with their probable errors to suggest that the difference is more than a chance one. It is probably explained by the fact that the 'models' type of test presents the problem in a more direct and concrete fashion than the explanation type, for in the latter the subject is obliged to read the description and question and relate them to the diagram before he can proceed with the mental operations connected with solving the problem which, as we show later, constitute the essential part of the test.

Difference observed with 'Diagrams' Type. The only other difference of any appreciable magnitude occurs in the case of the mechanical diagrams test when employed with the elementary groups. Here the average correlation between the halves of the test falls to $\cdot 48 \pm \cdot 06$. It differs from the corresponding figure for the models test by $\cdot 23 \pm \cdot 063$, and from the completion test by $\cdot 20 \pm \cdot 072$. These differences, while large enough to suggest the unlikelihood of their being solely of chance occurrence, are not sufficiently in excess of their probable errors to place the matter beyond doubt. We have, however, already suggested that the abstract nature of the diagrams may have caused the somewhat lower reliability which the mechanical diagram test appeared to exhibit with the younger groups of the elementary school. This same cause would explain the similar difference observed above between this test and the other tests.

RELIABILITY OF A TEAM OF TESTS

(1) *With the Commerce Subjects.* We show later that the mechanical models, explanation, completion and

diagrams tests involve a common group factor. It is therefore of interest to inquire into the reliability we may expect from a team of these tests if employed to measure this factor. We have done this by 'pooling' the eight tests taken by the commerce groups into two teams of four each, viz. M_1, M_3, E_2, EC, and M_2, M_4 E_1, D, and determining the correlation between them.[1] This works out to the high figures of ·94 for the first group and ·90 for the second group.

(2) *With the Elementary Subjects.* It was not possible to divide the tests taken by the elementary school boys in the same way, since these numbered only six, and were not identical with those taken by the commerce subjects. We can, however, select from these six one of each of our four types of test, and so get a team roughly comparable with those just mentioned. The theoretical correlation of such a team with another similar one, based on the reliability and inter-correlation of the tests themselves, is again high, viz. ·86.

CONCLUDING OBSERVATIONS

Utility of the Tests. It has been shown that in the case of each of the tests involving 'mechanical' operations, whose reliability we have now examined, there is a tendency for persons who do well in one sub-test to do well in another, and vice versa. That is to say, each pair of sub-tests involves some common mental quality or qualities in respect to which individuals differ, and differences in the scores made at these sub-tests are not attributable wholly to chance but provide some index of an individual's capabilities at the kind of work involved. Seeing that, in the case of every one of these tests, each sub-test correlates with all the others, it is reasonable to suppose that the whole test provides, in each case, a more exhaustive measure of whatever mental quality (or

[1] By Spearman's formula for the correlation of sums, *Brit. Jour. of Psych.*, v, 417.

qualities) it may involve than does any single sub-test, as is indeed suggested by the higher correlation between the halves of the test as compared with that between the individual sub-tests. We have seen, further, that each test score measures the kind of activity involved in the test with a fair degree of reliability which may be still further increased by increasing the number of tests, or by employing a team of tests where this is justified. So far, then, as the correlational criteria go they promise well for the employment of the tests as measuring instruments. It may be added that so far as could be judged from our observations when giving and scoring the tests, and from conversations with the subjects, their use should present no practical difficulty. No single test would, of course, provide a perfect measure, since in no case does the reliability reach unity; nor could we expect it to do so. In order to obtain a sufficiently accurate measurement for practical purposes a number of tests must be given—just how many is a question to be considered later.

Further Questions. It should be remembered that the present chapter is concerned solely with the question as to whether the tests indicate the existence of individual differences in ability to carry out the mental operations which they severally involve, and how far the scores may be relied on to indicate such differences. We have yet to determine what are the 'abilities' or mental qualities upon which these operations depend, and in respect to which individuals may be measured. The objective aspect of this question forms the topic of our next chapter. In the event of a test involving more than one such ability there remains to be answered the further question as to how these abilities may be independently measured—a question not to be confused with that concerning the reliability of the whole test score as studied in the present chapter.

CHAPTER VII

EVIDENCE FOR A 'SPECIAL ABILITY' OR GROUP FACTOR

THE ISSUE INVOLVED

THE Question. The question now arises,—what are the essential qualities which the tests examined in the last chapter have been shown to measure? Does, for example, each of the various types of test employed measure the same quality (or qualities), and if so, is it the same quality as makes for success at the school examinations, or at the 'intelligence' tests, or at any of the other activities which we have attempted to measure? To put the question more technically—what are the 'factors' involved in our tests, and, in particular, to what extent do they provide evidence of the existence of the special 'mechanical' factor to which we referred in Chapter III?

Criteria. To answer this we must first inquire to what extent ability at any one of the activities concerned goes with ability at any other. In this way we may compare the various tests with one another and with the school examinations, and each of these again with the various estimates that we have collected. Where two activities call in large measure for the same mental quality (or qualities), we should expect those who do well in one to do well in the other, and vice versa. A ready means of determining the extent of such agreement is provided by the correlation coefficient. Such coefficients have been calculated

for our data and are given in Tables XI–XIX of the Appendix.

While these coefficients afford some indication of the extent to which any single pair of measurements selected from the table may depend on common mental qualities, they provide no evidence, in themselves, as to what those qualities may be. For example, it does not follow that because three tests, A, B and C, inter-correlate, that all three involve the same quality, but only that each pair has something in common: the qualities in A may be (say) *ab*, in B *bc*, and in C *ca*. On the other hand, if all these tests did involve one and the same common quality we should expect them to correlate with each other.

In view of what has been said about the theory of *g*,[1] some correlation may always be expected. This being so, the really interesting point is whether the coefficients indicate the presence of other factors in our tests.

A special criterion is needed for determining this, and has been applied to the data relating to our larger groups of Series II and III. But even our first series of experiments bring out certain interesting points bearing on this question. We shall therefore examine all three sets of data in turn.

SERIES I—COMMERCE STUDENTS.

Examination of Data. Tables XI–XV give the inter-correlations between the tests taken by the commerce students. An examination of these brings out the following points:

(1) Those tests in which mechanical movements are involved, viz. tests M_1, M_2, M_3, M_4, E_1, E_2, EC and D,[2] exhibit high correlation with one another. We will call these the 'M' group; their inter-correlations are marked off from the other coefficients in the tables by the square

[1] See p. 36. [2] For descriptions of these, see Chapter V.

'M'. The average inter-correlation of this group of tests is seen to be ·69, ·76 and ·68 for the three groups of subjects respectively.

(2) The correlation of the 'Knots' test (K) with the M group is decidedly lower, the average being only ·29—·01 and ·44 for the respective groups.

(3) Group II subjects, it will be remembered, took also an 'intelligence' test (G). Reference to Table XII shows that this, too, correlates much lower (average ·21) with the M group than do the M tests with one another.

(4) The same table shows that K and G correlate more with one another than do either with the M tests.

(5) These same differences as between the M and K tests are brought out when we separate the boys from the girls of Groups II and III, and make them into an A and B group respectively (Tables XIV and XV).

Conclusion. Viewing the results as a whole it is clear that each M test has more in common with any other M test than with either K or G. If the M tests were merely better measures of the same quality (or qualities) as causes K to correlate with G we should expect these latter tests to correlate at least as highly with the M group as with each other. As this is not the case, it would seem that involved in each M test is some additional quality (or qualities) over and above any it may measure in common with K and G, to which its markedly higher correlation with the other M tests must be attributed.

Such a view is, of course, only tenable provided the observed differences in the correlation coefficients are 'significant' when considered in relation to their 'probable errors'. In the experiments which follow such errors have been taken into account by the application of a criterion specially devised for this purpose. The present experiments were of a preliminary nature in which our main object was to 'test' the tests, and hardly provide suitable data for applying this criterion. Here, then, we only remark that the differences are large and the con-

clusions which they suggest are in agreement with those at which we definitely arrive later.

SERIES II.—ELEMENTARY SCHOOL BOYS

I. General Survey of the Correlations

(1) *M tests compared with School Examinations.* In Table XVI we are able to compare, in the case of our 114 elementary school boys, ability at the M tests with ability at the school subjects as measured by three separate comprehensive school examinations.[1] This table has been derived (by averaging) from three similar tables drawn up in respect of each of the three school classes into which our subjects were divided. By so doing we have secured greater homogeneity with regard to age, general development and training, than would have been the case had all our subjects been treated as a single group. As it is, it will be seen that our tests show no correlation with age. The tables for the three separate classes exhibit the same features as we are about to notice in Table XVI. A glance at this table brings out the following points:

(*a*) The M tests exhibit a fairly high degree of correlation with one another. In every instance the correlation of one M test with another exceeds 4½ times its p.e. The average correlation of one M test with another (i.e. the average of square M) is ·47. In this respect the present result corroborates that of Series I.

(*b*) The three school examinations—X_1, X_2, X_3—also show quite definite correlation with one another, the lowest coefficient, ·40, being well over 4½ times its p.e. The average correlation of one examination with another (i.e. of square E) is ·47.

(*c*) The correlation of the M tests with school examinations is, on the contrary, decidedly low throughout, being on an average only ·19.

[1] Briefly described on p. 48. They are denoted here, and henceforth, by the letter X.

For purposes of comparison, the corresponding figures for the three separate classes whence Table XVI has been derived are given below:

AVERAGE CORRELATIONS

Subjects	M v. M	Exams. v. Exams.	M v. Exams.
Group IV	·58	·37	·21
Group V	·44	·46	·12
Group VI	·38	·59	·23

It is evident that if these differences are 'significant' the M tests have more in common with one another than with the school examinations, and vice versa.

(2) *Various Measures of 'Ingenuity' compared with the M Tests and School Examinations.* Fifty-nine of our school boys attended a woodwork centre and we were able to obtain from the boys' instructor an estimate of their 'ingenuity' and 'originality' as manifested in their work at (1) woodwork and (2) technical drawing.[1] In making his estimate the instructor was naturally guided by the actual marks which the boys had obtained from time to time in the subjects. At the same time he was asked to give weight to ability to understand the work and to originate ideas about it, rather than to care and skill in executing it. The items referred to as woodwork and drawing may therefore be regarded as largely estimates of the same mental trait—a fact which probably accounts for their high correlation with each other of ·84. Their correlations with the M tests and the school examinations, and also the inter-correlation of these latter for the same group of 59 boys, are given in Table XVII. Age was found to correlate to the almost negligible extent of ·14 with woodwork, and of ·18 with drawing. Its influence has been eliminated in the coefficients of Table XVII,[2] although, as a matter of fact, the greatest difference made anywhere by such elimination did not exceed ·01 in the drawing

[1] For descriptions of these estimates, see p. 48.
[2] By Yule's method of partial correlation.

coefficients, and leaves the woodwork coefficients unchanged within the two decimal places given.

It is seen that both woodwork and technical drawing exhibit marked correlation with the M tests ; of the twelve coefficients, ten well exceeded $4\frac{1}{2}$ times their p.e.s. The average correlation (rectangle A) amounts to ·42. On the other hand these two subjects have little correlation with the school examinations, the coefficients here (rectangle B) falling to an average of ·11. Clearly ability at woodwork and technical drawing goes far more closely with ability at the various M tests than with ability at the school examinations.

A similar result is seen in the estimates of ingenuity based on 'Home Handicraft' (H) and 'School Handicraft' (S), for which, it will be remembered, the teacher of Group IV (our top class) graded his pupils. Age was found to play some part in determining these estimates, its correlation with home handicraft being ·40 and with school handwork ·50. Consequently its influence has been eliminated by the method of partial correlation in the coefficients of Table XVIII. The average correlation of the estimates with the M tests reaches ·32, but falls to ·07 with the school examinations.

The two estimates, however, do not correlate very highly with one another (·27). This is partly due to the above-mentioned influence of 'age', for the two lists as originally supplied by the class teacher, i.e. before eliminating the influence of age, correlate to the extent of ·41. It seems also partly due to the admitted difficulty which the teachers found in grading this kind of ability. It is also seen that with this group of subjects one of the school examinations (X_2) has little correlation with the other two and is, in this sense, unreliable. Notwithstanding these difficulties, it will be shown by the criterion employed later that the higher correlation of these estimates of ingenuity with the M tests as compared with the school examinations is not without significance.

II. Criterion for a Single Common Factor

(1) *Need of a Criterion.* We have seen that in accordance with the theory of *g* some correlation between all our various mental measurements would be expected on account of the factor *g*, upon which every kind of cognitive activity is held partly to depend. The results just examined suggest that over and above any such factor common to the whole of our data, there may be another factor (or possibly factors) which restricts its influence to the M tests and such measures of 'ingenuity' as we were able to obtain, and which would account for the much higher correlations observed between the various members of this group of measurements as compared with their correlations with the school examinations. Such a factor, confined as it would be to a limited range of activities, may be called a 'group' factor in contradistinction to the 'general' factor (*g*) which runs throughout the whole gamut of cognitive operations. Alternatively, there may be a 'group' factor running through the school examinations, or even two such factors, one within the M group, the other within the examination group. But since this inference as regards group factors is based upon observed differences between correlation coefficients, it is clear that before it can be considered valid these differences must be shown to be 'significant' when considered in relation to their 'probable errors'.[1] Consequently we must apply to our data the criterion which has been specially devised for answering this question, and which may be stated as follows.

(2) *Statement of Criterion.* Let the inter-correlation between four tests, a, b, p, q, be denoted by r_{ap}, r_{aq}, r_{bp} and r_{bq}. It has been shown that each and all of these correlations are necessarily attributable to a single common factor when $\frac{r_{ap}}{r_{aq}} = \frac{r_{bp}}{r_{bq}}$, or, what amounts to the same thing more

[1] I.e. it must be shown that the difference between the correlation coefficients is not likely to have arisen by 'chance'

conveniently expressed, when $r_{ap}.r_{bq}-r_{aq}.r_{bp}$ (called the tetrad-difference) $= 0$; and conversely, when each of these correlations are due to the same common factor, then the tetrad-difference will be zero.[1] While this criterion rigidly defines the common factor as 'single', i.e. as functioning as a unitary whole, it does not prevent its being conceived (if circumstances warrant) as complex in nature.

(3) *The Probable Error of the Tetrad-difference.* Let $r_{ap}.r_{bq} - r_{aq}.r_{bp} = F$. Now while theory demands that F shall equal zero, in actual practice each correlation coefficient contains a 'sampling' error, and consequently so does F.[2] Hence even when the condition for a single common factor holds theoretically the experimental value of F will tend towards some small positive or negative value rather than zero, and we must therefore inquire whether such value may, or not, be attributed to 'chance' or accidental circumstances. This will depend on its 'sampling' (or 'probable') error. The method of calculating this has been shown by Spearman and Holzinger.[3]

(4) *Application to more than Four Tests.* If we wish to apply the criterion to a group of more than four tests we must calculate the value of every possible tetrad-difference obtainable from the whole group, together with its prob-

[1] Demonstrated by Prof. C. Spearman, *Proc. Roy. Soc.* A, Vol. ci, 1922, pp. 97–100.

[2] The theoretical value of (say) r_{ap} is the average of an infinite number of similar 'r_{ap}s'. Any given r_{ap} is merely a 'sample' of this infinite number, and consequently will tend to deviate by 'chance' from this theoretical average value. The extent of its deviation is regulated by the law of error, and measured by its 'probable' or 'sampling' error. In accordance with this law, there are even chances that a randomly chosen sample will deviate negatively or positively from the theoretical average value of all such samples by an amount equal to its probable error (p.e.). We are hardly safe in ascribing an observed deviation to other than 'chance' or accidental causes unless it exceeds $4\frac{1}{2}$ times its p.e.

[3] In *Brit. Jour. of Psych.*, vol. xv, p. 17, and vol. xvi, p. 86.

able error. If there were one and only one factor common to the group, then, by the above criterion, the theoretical values of all these tetrad-differences would be zero. But in view of what has been said with respect to the sampling error their actual values, divided in each case by their probable errors, would tend to distribute themselves normally around zero in agreement with the law of error. The dotted curve N of Fig. 3 [1] shows the ideal shape to which the frequency curve of such a distribution would tend to conform. About half the values fall within the limits of $\pm$ the probable error, while very few indeed—under 1 in 1340—exceed 5 p.e. in either direction. The test for a single common factor will be whether this distribution of F is actually obtained.

(5) *The Case of a Group Factor.* Consider now the case where $r_{ap}.r_{bq}$ is definitely greater than $r_{aq}.r_{bp}$. This will occur when r_{ap} or r_{bq} (or both) is too large compared with the other coefficients to be accounted for entirely by the same factor as that causing r_{aq} or r_{bp}. In this case a and p, or b and q (or possibly both), are said to exhibit super-correlation, and the cause of this must be sought in some factor (or factors) common only to the pair in which the super-correlation occurs.[2] The same may be said, of course, of r_{aq} and r_{bp} when their product exceeds $r_{ap}.r_{bq}$. The F's derived from tetrads such as these will no longer tend to a chance distribution around zero, but will tend to some significant value. It is clear that when, of a number of tests, some involve a factor common to themselves only, i.e. a 'group' factor, causing super-correlation where it occurs, this will become evident by the tendency of the F's to distribute themselves more widely on either side of zero than could be attributed to chance. This significant

[1] P. 118.

[2] It will be seen that when both r_{ap} and r_{bq} exhibit super-correlation, this cannot be attributed to the same factor in each case, since then this high correlation would also occur in r_{aq} and r_{bp}, and F would tend to become 'insignificant'.

increase in the scatter of the F's, then, will indicate the presence of one or more group factors in the tests from which the F's have been obtained.[1] A, of Fig. 3, is a frequency curve of such a distribution. In this, a larger proportion of F's fall beyond the limits expected from mere sampling than could be attributed to accidental or chance circumstances.

(6) *'Undirected' and 'Directed' Tetrad-differences.* Consider the tetrad $\frac{r_{ap}}{r_{aq}} \frown \frac{r_{bp}}{r_{bq}}$. In arriving at the tetrad-difference (F) there are two ways in which the products may be taken, viz. $r_{ap}.r_{bq} - r_{bp}.r_{aq}$, and $r_{bp}.r_{aq} - r_{ap}.r_{bq}$, giving two values of F, equal in magnitude but opposite in sign. In obtaining a frequency-distribution of F from a table of correlation coefficients, both values of F must be included if we are to avoid introducing a special direction or bias into our data. In this case the difference may be said to be 'undirected', and the frequency curve will, of course, be always symmetrical with respect to the zero ordinate.

If, on the other hand, there is a particular reason for always taking the products in the same order, as when, for example, it is required to see whether the product of the top left-hand member and the bottom right-hand member always exceeds that of the top right-hand member and the bottom left-hand member, in a given set of tetrads, there is, of course, justification for so doing, provided it be remembered that the resulting distribution of F represents only half the complete data. In this case the F's may be said to be 'directed', and only one value of F will, of course, be obtained for each tetrad. A of Fig. 4[2] is a frequency curve of such a distribution.

III. Application of the Criterion

(1) *The M Tests compared with each other.* Let us first inquire whether the inter-correlations of the M tests alone

[1] Its precise location and nature must, of course, be sought in an analysis of the data.

[2] P. 118.

indicate, in the light of the above-described criterion, the presence of more than one common factor. For this purpose we must calculate the value of all possible tetrad-differences derivable from square M in Table XVI, together with their probable errors.[1] For example, taking the four tests M_5, M_6, M_7, E_3, we get, $F = \pm r_{M_6M_5} \cdot r_{M_7E_3} \mp r_{M_7M_5} \cdot r_{M_6E_3} = \pm (\cdot 53 \times \cdot 36) \mp (\cdot 63 \times \cdot 27) = \pm \cdot 0207$.

Proceeding in this way with every tetrad in square M, and dividing each F by its probable error, the following distribution of the 90 values of F/p.e. is obtained:

TABLE A. 114 SUBJECTS

					−	+				
Mid-value F/p.e.	4·5	3·5	2·5	1·5	·5	·5	1·5	2·5	3·5	4·5
Frequency . .	1	13	4	8	19	19	8	4	13	1

In the case of a normal distribution only about 45 of the F's should fall outside the limits of ± their p.e. Actually 58 do so. Thirty-two of these exceed thrice their p.e., whereas in a normal distribution about 6 cases only would be expected; 10 of the cases exceed four times their p.e., and so tend to become 'significant' in the statistical sense of the term. As a whole, then, the scatter of the F's in this distribution exceeds the limits expected of mere sampling errors. This means that at least some of the M tests correlate with other M tests to a higher degree than can be attributed solely to a general common factor running through them all. The simplest explanation of such super-correlation, and one that accords best with the results yet to be considered, is that running through all these tests are two common factors, namely the general factor, *g*, which we should expect to find in accordance with the theory of *g*, and another factor which we may provisionally

[1] These were calculated by formula (1) given by Spearman and Holzinger in *Brit. Jour. of Psych.*, 1925, xvi, 86. Since, however, our coefficients were calculated by the 'rank' method (squared differences), the probable error was taken as ·7063 times its standard deviation,

call m; but that the relative influence of these two factors varies from test to test. Suppose, for example, that of four M tests, 1 and 3 have large m and small g, while 2 and 4 have small m and large g. Then r_{13} and r_{24} will tend to be larger than r_{23} and r_{14} and the tetrad-differences will tend to become 'significant'. Where, on the other hand, the four tests have about the same m and g, their tetrad-differences will tend to zero. The distribution of F's derived from such a 'population' will tend to scatter themselves in much the same way as actually occurs above.

(2) *M Tests compared with 'School Examinations'*. Suppose now that two of the M tests in the above-considered tetrads be replaced by two tests in which m is absent. If our explanation is correct we should expect the resulting F's to deviate from the values expected by 'chance' even more widely than before, since now two of the members of the tetrad should correlate much more highly with one another on account of the common m than with the other two tests. If, moreover, we 'direct' the tetrad-differences so that they are always taken in the order $r_{m_1m_2} \cdot r_{x_1x_2} - r_{m_1x_2} \cdot r_{m_2x_1}$, where the m's are any two M tests, the x's any two school examinations, the resulting F's should tend always to a positive value on account of the super-correlation between m_1 and m_2. Let us substitute two of the 'school examinations' for two M tests and see if this results. The following table shows the distribution of all such F's (divided by their p.e.s) derived from Table XVI.

TABLE B. 114 SUBJECTS

$$F = r_{m_1m_2} \cdot r_{x_1x_2} - r_{m_1x_2} \cdot r_{m_2x_1}$$

Mid-value F/p.e.	+·5	1·5	2·5	3·5	4·5	5·5	6·5	7·5	8·5	9·5
Frequency . .	—	1	9	13	19	17	17	3	7	4

In every case the tetrad-difference is positive, i.e. the product in which the coefficient of the type $r_{m_1m_2}$ occurs, viz. $r_{m_1m_2} \cdot r_{x_1x_2}$ exceeds the product $r_{m_1x_2} \cdot r_{m_2x_1}$. Of the 90 F's, 48 exceed 5 times their probable error. The F's are

equally distributed on either side of a value equal to about 5·2 times their probable error as compared with the zero expected in the case of a 'chance' distribution. Here, then, is overwhelming evidence of a group factor (or factors).[1] Without further considerations it would be impossible to say whether such a factor resides in the M tests, or in the 'school examinations', or even in both, for any of these alternatives would tend to give rise to the above type of distribution. But we should expect the position at the school examinations to depend very largely on *g*, particularly in view of the large variety of school subjects which entered into those examinations, whereby other factors than *g* would tend to mutual cancellation. It is therefore extremely unlikely that the school examinations involve a group factor large enough to account for the whole of the super-correlation evident in Table B.[2] Unless we accept this view we must suppose that the correlations of the M tests with one another and (as we show later) with the various criteria of 'ingenuity' which we have collected are due to *g*, while the correlations of the school examinations with one another depend largely on some group factor,—i.e. that the M tests, drawing and handwork, are better tests of general intelligence than the school examinations. Such a supposition not only contradicts the facts of Tables A and E, and is opposed to the low correlation between the M and *g* tests found with the commerce groups, but is contrary to experience. On the other hand the 'pooling' of diverse tests whereby the influence of *g* tends to be augmented was specially avoided in the M tests. Table A has already provided some

[1] We show later that the super-correlation here observed is best accounted for by a broad group factor running through the tests rather than by a number of independent group factors.

[2] Such a factor has not hitherto been discovered, and is contrary to our present knowledge of the factors in school subjects. See, for example, N. Carey, 'Factors in the Mental Processes of School Children', *Brit. Jour. of Psych.*, viii; and C. Burt, *The Distributions and Relations of Educational Abilities.*

evidence of a group factor (or factors) in these tests. The super-correlation observed in Table B is therefore best accounted for by this same group factor m, which now, owing to the introduction into the tetrad of two members (school examinations) which do not contain m, comes out much more clearly than in Table A—a result which we anticipated in our previous section. Further corroboration of this view will be found in the subjective analysis of the tests, and in the distribution of tetrad-differences derived from various measures of 'ingenuity' which we must now consider.

(3) *M Tests and Estimates of 'Ingenuity' (taken together) compared with School Examinations.* Now let one of the estimates of 'ingenuity', such as 'handwork', be substituted for one of the M tests in our last group of tetrads, so that the general form of F becomes $r_{mi} . r_{x_1x_2} - r_{mx_2} . r_{ix_1}$, where i is any one of our estimates of ingenuity, x and m remaining as before. If there is a group factor common to the M tests and the estimates, and we 'direct' the tetrad-differences so that products are always taken in the order just given, such F's will tend to be positive on account of the super-correlation in r_{mi}, and their distribution will tend to resemble that in Table B.[1] Four estimates are available for this purpose, viz. the 'woodwork' and 'technical drawing' of Table XVII, the 'home handicraft' and the 'school handicraft' of Table XVIII.[2]

[1] The improbability of the group factor residing in the school examinations has already been discussed on p. 113.

[2] In this table there is practically no correlation between x_1 and x_2. It is clear that in order to compare ability at the tests and estimates with ability at the examinations (for super-correlation) it is necessary that the examinations should themselves measure something in common. For this reason we have not included the coefficient $r_{x_1x_2}$ (·06) in extracting the tetrads from Table XVIII. All examination coefficients, however, have been included in arriving at Tables XVI and XVII. If x_2 be omitted from these on account of 'unreliability', the group factor comes out even more clearly.

Making the above proposed substitution with each of these estimates in turn, we get the following distribution of F/p.e.,—here 'woodwork' is indicated by *w*, 'technical drawing' by *d*, 'home handicraft' by *h*, and 'school handwork' by *s*:

TABLE C

	− ·5	+ ·5	1·5	2·5	3·5	4·5	5·5	6·6	Central value (approx.)
Mid-value F/p.e. . . .	·5	·5	1·5	2·5	3·5	4·5	5·5	6·6	
$F = r_{mw} r_{x_1x_2} - r_{mx_2} \cdot r_{wx_1}$ Frecy.			6	8	7	11	4		3·5
$F = r_{md} \cdot r_{x_1x_2} - r_{mx_2} \cdot r_{dx_1}$,,			2	6	9	7	11	1	4
$F = r_{mh} \cdot r_{x_1x_2} - r_{mx_2} \cdot r_{hx_1}$,,		4	5	5	2	2	0	6	2·5
$F = r_{ms} \cdot r_{x_1x_2} - r_{mx_2} \cdot r_{sx_1}$,,	1	7	6	3	5	0	2		1·7
Total	1	11	19	22	23	20	17	7	3·3

With but one exception all the F's are positive, as was anticipated, and are distributed in each case around a value (shown in the last column) which departs markedly from zero. In view of what has already been said,[1] and in the light of Table D yet to be examined, the super-correlation thus shown is again best accounted for by the presence of a group factor (or factors)[2] in the M tests and the estimates of ingenuity.

(4) *Estimates of Ingenuity compared with School Examinations.* We may now displace the remaining M tests in our last tetrads by another estimate of ingenuity, so that F becomes $r_{i_1i_2} \cdot r_{x_1x_2} - r_{i_1x_2} \cdot r_{i_2x_1}$, where the *i*'s are the ingenuity estimates, and the *x*'s are the school examinations. Six such tetrads are available from Table XVII, and four from Table XVIII.[3] Their distribution is as follows. The subscripts represent the same estimates as before, and the F's are 'directed' as shown.

TABLE D

	+ ·5	1·5	2·5	3·5	4·5	5·5	6·5	7·5	8·5
Mid-value F/p.e. . . .	·5	1·5	2·5	3·5	4·5	5·5	6·5	7·5	8·5
$F = r_{wd} \cdot r_{x_1x_2} - r_{wx_2} \cdot r_{dx_1}$ Frecy.				1	1	0	0	2	2
$F = r_{hs} \cdot r_{x_1x_2} - r_{hx_2} \cdot r_{sx_1}$,,		2	0	2					

[1] On p. 113 in reference to the group factor in the M tests.

[2] See footnote [1] to p. 113.

[3] See footnote [2] to p. 114.

Again there is clear proof of super-correlation. Seeing that we have already had evidence of a group factor common to the M tests and the estimates of ingenuity, this super-correlation is best explained, at least in part, by the same group factor running through the estimates themselves.

(5) *M Tests and Estimates considered together.* Finally, we may consider tetrads of the form $F = r_{m_1 i} \cdot r_{m_2 m_3} - r_{m_1 m_3} \cdot r_{i m_2}$. Such tetrads differ from those which we first considered—under (1) above—in that one of the M tests is displaced by one of the estimates of ingenuity. If our reasoning has been correct, a group factor runs through all four members of such tetrads. Consequently the F's derived from them will not necessarily indicate its presence, since now there is no a priori reason why the products of one pair of coefficients should exceed that of the other pair. But if the influence of the group factor varies from one test to another, so that some involve this factor to a greater extent, but the general factor g to a less extent, than others, a tendency to deviate from zero beyond the limits set by 'chance' might be observed even in the distribution of these F's, as was seen in the case of Table A. It is therefore of some interest to examine such distributions. This time we have no reason for giving a special 'direction' to the tetrad-differences, so that we have two F's, of equal magnitude but of opposite sign, for each tetrad. The distributions are as follows, the subscripts indicating the same kind of tests and estimates as hitherto:

TABLE E

Mid-value F/p.e. (+ and −)	·5	1·5	2·5	3·5	4·5	5·5
$F = r_{m_1 w} \cdot r_{m_2 m_3} - r_{m_1 m_3} \cdot r_{w m_2}$	18	22	14	5	1	
$F = r_{m_1 d} \cdot r_{m_2 m_3} - r_{m_1 m_3} \cdot r_{d m_2}$	22	10	11	10	4	3
$F = r_{m_1 h} \cdot r_{m_2 m_3} - r_{m_1 m_3} \cdot r_{h m_2}$	19	16	7	14	4	
$F = r_{m_1 s} \cdot r_{m_2 m_3} - r_{m_1 m_3} \cdot r_{s m_2}$	27	12	9	10	2	
Total	86	60	41	39	11	3

Of the 480 tetrad-differences, only 86 fall within the limits of ± their probable errors, and far more exceed 4 p.e. than could be explained by 'chance'. Here, again, are clear signs of super-correlation, although for reasons given above not so marked as in Tables B–D. The general character of the distribution resembles that of Table A, as is to be expected if the estimates of ingenuity involve the same factors as the tests.

(6) *Summary*. Our results, so far, may be summarized by adding together (1) Tables A and E, and (2) Tables B, C and D. By so doing we get two tables which show, respectively, the distribution of those F's where we have reason for thinking the group factor runs through all four members of the tetrad, and to which no special 'direction' has been given, and the distribution of those where the group factor is involved in only two of the four members and which have consequently been 'directed'. They are as follows, where t stands for any of the M tests or estimates of ingenuity, and x for any of the school examinations:

TABLE F

$$F = \pm r_{t_1t_2} \cdot r_{t_3t_4} \mp r_{t_1t_4} \cdot r_{t_2t_3}.$$

					−	+					
5·5	4·5	3·5	2·5	1·5	·5	·5	1·5	2·5	3·5	4·5	5·5
3	12	52	45	68	105	105	68	45	52	12	3

TABLE G

$$F = r_{t_1t_2} \cdot r_{x_1x_2} - r_{t_1x_2} \cdot r_{t_2x_1}.$$

−	+									
·5	·5	1·5	2·5	3·5	4·5	5·5	6·5	7·5	8·5	9·5
1	11	22	31	39	40	34	24	5	9	4

The difference between these two distributions and that of 'chance' frequency is clearly shown in Figs. 3 and 4.

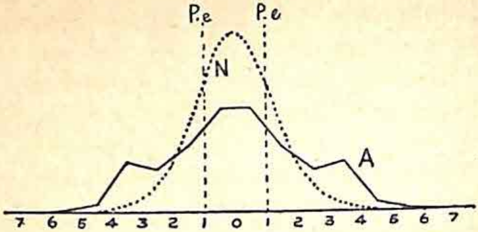


FIG. 3.

Frequency distribution of Table F. 'Undirected' tetrads of which all four members are 'mechanical' tests or estimates.

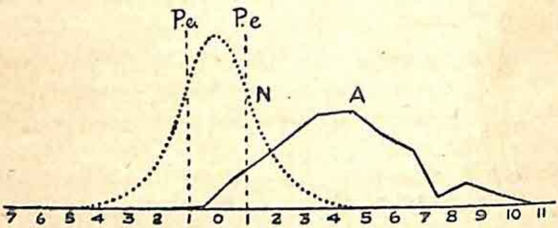


FIG. 4.

Frequency distribution of Table G. 'Directed' tetrads of which two members are 'mechanical' tests or estimates, and two are elementary school examinations.

SERIES III.—TRAINED MECHANICS

I. General Survey of Data

We turn now to our third set of results. The inter-correlation of the various tests and examinations taken by the 228 students of the R.A.F. School, Cranwell, who were passing out as trained mechanics, will be found in Table XIX. These tests have already been described in Chapter V. Reference to this chapter will show that the data, here, fall naturally into three groups, viz. (1) a group in which the material is largely spacial and 'mechanical' in character, namely the two M tests (E_3 and M), Part II of the Air Ministry's Mental Efficiency Test (A_2),

and the examination in Trade Knowledge (T); (2) two 'intelligence' tests, namely Professor Spearman's test (I) specially devised to test general intelligence, and Part I of the Air Ministry's Mental Efficiency Test (A_1), which was of a kind often included in a 'battery' of intelligence tests and involved neither spacial material nor mechanisms; and finally, (3) the examination in the subjects of the school curriculum (S).

It is seen (Table XIX) that all the members of these groups exhibit a fair degree of correlation with one another, for in only three cases does the coefficient fall below $4\frac{1}{2}$ times its p.e. This means that every pair of tests in the table measures something in common. The latter may reasonably be taken to be the general factor (*g*) which has been found to be involved in all cognitive operations.

But the members of the mechanical group correlate higher with one another than with the 'intelligence' tests, the average of square A (Table XIX) being ·43, but of rectangle B only ·27. The correlation between the intelligence tests rises again to ·41. Provided these observed differences are not due to mere chance they suggest that the 'mechanical' group have more in common with one another than with the 'intelligence' tests, and vice versa, i.e. that over and above *g* there is involved in either the 'mechanical' group or the 'intelligence' tests (or both) a 'special' ability or group factor. To determine whether this is so we must apply the criterion as before.

II. Application of the Criterion

(1) *The 'Mechanical' Group compared with the 'Intelligence' Tests.* To bring such a factor most clearly to light we must examine tetrad-differences of the kind $r_{m_1m_2}.r_{i_1i_2} - r_{m_1i_2}.r_{m_1i_2}$, where the m's are any two of the 'mechanical' group, and the i's are the two 'intelligence' tests. The distribution of all such differences derivable from Table XIX, and 'directed' as indicated above, is as follows:

TABLE H. 228 SUBJECTS

Mid-value F/p.e. .	+2·5	3·5	4·5	5·5	6·5	7·5
Frequency . . .	1	4	2	3	1	1

The values of F are seen to depart widely from the zero which theory demands if the correlations are to be explained solely by a single factor common to all the tests concerned. In every case the product involving $r_{m_1m_2}$ exceeds the other. Again, then, the presence of a group factor clearly emerges. We have no reason to suspect such a factor in the 'intelligence' tests. The 'mechanical' group, on the other hand, consists of two tests (the M tests) in which we have already had evidence of a group factor, and two others in which similar mental operations are involved. The factor, then, would seem to be located in the 'mechanical' rather than in the 'intelligence' tests and is most reasonably identified with the same as came to light in the experiments of Series II.

A comparison of Table H with Table B shows that the influence of this factor is not quite so marked in the present experiments. Several causes may have contributed to this. To mention two only, our subjects of Series III were selected and trained for the special kind of work into which the group factor, if we have correctly located it, enters. Consequently we should expect the individual differences with respect to this factor to be smaller here than among the elementary school subjects, and correspondingly harder to measure. Again in the experiments under review only two members of the 'mechanical' group were specially devised to test for the group factor, viz. the two M tests, while no fewer than six were given to the elementary groups. It appears from the table of 'specific' correlations (Table XXIV) that these two M tests involve the group factor to a larger extent, if anything, than either of the other members of the 'mechanical' group; while one of the latter (A_2) would seem to involve g to a larger extent than the M tests (Table XXI).

(2) *Technical School Subjects compared with the other*

Tests. It is seen, in Table XIX, that the examination in the technical subjects of the school curriculum (S) has much in common with the 'intelligence' tests. But it correlates higher with the technical group than do the latter. Is this higher correlation, we may ask, due to 'chance', or to variations in the influence of *g*, or does it indicate a group factor? To decide this we must investigate tetrad-differences of the kind $F = r_{mS} . r_{IA_1} - r_{mA_1} . r_{SI}$, where *m* is any one of the 'mechanical' group, S the school subjects, I and A_1 the 'intelligence' tests, of Table XIX. The distribution of such differences, specially 'directed' as above, is as follows:

TABLE I. 228 SUBJECTS

	+					
Mid-value F/p.e. .	2·5	3·5	4·5	5·5	6·5	7·5
Frequency . . .	1	2	2	0	2	1

In every case the tetrad-difference, thus 'directed', is positive, and no fewer than five out of eight exceed four p.e. This super-correlation is best accounted for by the same group factor already noticed in the mechanical group extending its influence to the technical subjects of the Passing Out Examination, and bringing about the higher correlation noticed above.

PROVISIONAL CONCLUSIONS

To sum up our evidence and provisional conclusions, the data which we have now considered fall into two broad divisions. We have, first, a group in which the subject is called upon to deal mentally with special material, involving to a large degree mechanical movements. The group is itself divisible into three parts, viz. (*a*) psychological tests in which special emphasis was given to this kind of material, namely our M tests and Part II of the Air Ministry's Mental Efficiency Test; (*b*) the teachers' estimates of their pupils' ability to carry out work of a kind in which this same sort of material largely enters;

and (*c*) the comprehensive examination in the practice and theory of their trade taken by the students of the R.A.F. School, and constituting Part II of the Passing Out Examination. If a special ability exists we should expect it to enter somewhere in this data. Secondly, we have a group in which there is little, if any, spacial or 'mechanical' material. This consists of (*a*) psychological tests commonly used to measure intelligence, one being a very comprehensive test of this kind; and (*b*) the examinations of the elementary school. Both of these we should expect to depend in large measure on 'general intelligence' rather than on any special ability. The technical subjects of the Passing Out Examination would seem to fall equally well into both of these groups.

Starting with the M tests, we saw in Chapter VI that each of these provided a definite measure of some mental quality or qualities. Raising, next, the question as to what these qualities were, we have seen, from their intercorrelation, that each of the M tests involves much in common with all the others, but far less in common with that part of our data in which general intelligence would seem to be the main factor. This difference comes out clearly whether we measure the untrained and unselected school boys, the commerce students, selected for business and commerce rather than for engineering, or the candidates at the Passing Out Examination, highly trained and selected for various branches of mechanical engineering. A similar difference is observable in the case of the estimates and the examination in Trade Knowledge. The tetrad-difference criterion has shown that these differences are not attributable to mere 'chance'.

This means that over and above the correlation running through the whole of our data and best attributed to the general or universal factor, *g*, there is a genuine amount of super-correlation which must be attributed to the presence of a factor (or factors [1]) common only to a portion

[1] So far as the present evidence goes.

of our data, i.e. to a group factor. We have already seen that such a factor would be expected to reside, if anywhere, in the above-mentioned 'mechanical' group. This view finds further support in the super-correlation which occurs in the 'mechanical' group itself.

The question as to whether the super-correlation is best accounted for by a single broad factor running through all the 'mechanical' data, or by a number of independent group factors, is considered in the next chapter. It may here be remarked, however, that in view of the relatively high inter-correlation which exists between the various parts of this data a large number of independent factors would hardly be expected, for, to take the extreme case, if the super-correlation were produced each time by a different factor, so many factors would be needed in each test that there would remain little in common between any single pair, and the correlation would tend to become very small.

With these considerations in mind, we conclude provisionally that success at the kind of work involved in our specially devised tests depends not only on 'general intelligence' but also on a 'special ability', which also enters into the technical side of the work of the mechanical engineering students, and in part determines the ability at the various forms of handicraft for which the elementary school boys were assessed by their teachers. Seeing that such an influence can only become manifest in conjunction with the general factor, and with such other ('specific') factors as may be involved in the concrete operation in which it, itself, appears, it is more appropriately referred to as a 'factor' than as an 'ability', and by some such name as *m*. Further confirmation and enlargement of this view is to be sought in the knowledge of the nature of *m*. The objective aspect of this question occupies our next chapter, while its subjective aspect will be considered in the one following.

CHAPTER VIII

OBJECTIVE DETERMINATION AND MEASUREMENT OF *m*

CORRELATIONS WITH *g*

(*a*) *Elementary School Data.* We have seen that there exists quite a definite correlation between all the various tests and other measures that have entered into our data. Thus, to consider first the results obtained with the elementary school groups and given in Table XVI, the M tests are here observed to correlate not only with each other, but also, to some extent, with the school examinations. This suggests that in addition to the group factor in the M tests, of which we have already had evidence, there is another factor running through the whole of our measurements to which this correlation between the M tests and the school examinations is due. In view of the vast amount of evidence which has now been collected in support of the theory of *g*, this factor seems most reasonably identified with the general factor itself.[1]

Now the inter-correlation of one M test with two school examinations yields three coefficients. If we assume, as seems justified in the light of our results, that there is no factor common to any pair of these tests other than the general factor running through all three, we may employ

[1] Whether or not we choose to do so, the data to be examined in this chapter hold so long as we attribute the correlation between the M tests and school examinations to some influence common to them all.

the coefficients to determine the correlation of each test with the general factor.[1] Since there are three examinations, three such 'triads' may be formed with each M test, yielding three values of r_{mg}, where *m* is any particular M test and *g* the general factor. These have been used to obtain the most probable value of the coefficient of correlation between the M test and *g*.[2] The correlation of each school examination with *g* was arrived at in a similar way, using, this time, the thirteen triads which were available in each case. The coefficients, known as coefficients of 'intellective saturation', are given in Table XX.

The correlations of the school examinations with the hypothetical *g* are seen to be very much higher than those of the M tests, the average in the former case being ·69, in the latter ·26. These figures do not, of course, bring fresh data to our problem, but give quantitative expression to a fact which has already been noticed indirectly, viz. that the school examinations are much more dependent on the common influence which we have associated with *g* than the M tests, and to the extent represented approximately by the coefficients. They also indicate that success at the M tests is not wholly determined by group or 'specific' factors peculiar to the work itself, but depend in part on the same ability as makes for success at the school examinations, and this to the extent represented by ·26.[3]

(*b*) *R.A.F. School Data.* The corresponding figures for the data obtained with our trained R.A.F. subjects,

[1] The method employed is described by Spearman in *The Abilities of Man*, Appendix, p. xvi, and is given in the Appendix of the present volume, p. 205.

[2] By the following more reliable method than that of simple averaging—

$$r^2_{mg} = \frac{r_{mx_1} \cdot r_{mx_2} + r_{mx_1} \cdot r_{mx_3} + r_{mx_2} \cdot r_{mx_3}}{r_{x_1x_2} + r_{x_1x_3} + r_{x_2x_3}}.$$

[3] Complete dependence would, of course, be represented by unity.

derived from Table XIX, are given in Table XXI. In this case, since we have only two measurements in the 'intelligence' group (I and A_1 of Table XIX), only one triad was available from which to calculate the correlation of each member of the 'mechanical' group with *g*.[1] For I and A_1 four values were obtainable, which were averaged to give r_{Ig} and r_{AIg}. For S, the subjects (mainly technical) of the Passing Out Examination, only one triad was again available. The value of r_{Sg} obtained from it is placed alone in the table since S has much in common with both groups of data.

As with the elementary groups, the tests and other measures in which the group factor occurs exhibit quite a definite correlation with the general factor, averaging ·41, though to a decidedly lower degree than the 'intelligence' tests, which average ·67. Of the mechanical group, A_2 (Part II of the Air Ministry's Mental Efficiency Test) appears to depend somewhat more on the general factor than do the others. This is possibly due to the particular form in which the subject was required to give his answers, for these involved the careful filling in of an answer sheet after reading instructions relating thereto which were, at times, somewhat complicated. The facility with which these instructions were carried out would be expected to depend largely on *g*, and certainly not on the particular mental operations involved in solving the mechanical problem itself. The figure for S (the examination in school subjects) is also higher than for the 'mechanical' group generally. This we should expect, for the theoretical knowledge and the bookwork required by this part of the examination, as also the general handling of the questions, would depend largely on *g*. This part of the Passing Out Examination provides an interesting comparison with T—that part which aimed at testing the candidate's efficiency as a practical craftsman. The former, theoretical, side

[1] If, as is necessary, we are to avoid the introduction of group or 'specific' factors into the triad.

of the students' work is seen to correlate higher with g than the latter.

'SPECIFIC' CORRELATION

(*a*) *Elementary School Data.* We may now employ the coefficients of Tables XX and XXI to determine how much correlation remains between the tests after the influence of the general factor has been eliminated.[1] This has been done in the case of the tests and examinations taken at the elementary school (Table XVI). The ensuing correlation coefficients are given in Table XXII. It is seen that quite a large 'specific' correlation [2] remains between the various M tests, but none of appreciable magnitude between these and the school examinations.

(*b*) *R.A.F. School Data.* Corresponding figures for the data relating to the R.A.F. mechanics are given in Table XXIV. Again a large amount of specific correlation remains between the various members of the 'mechanical' group, but practically none between these and the 'intelligence' tests, or between the latter themselves. Such specific correlation, as also that noticed above in Table XXII, is in keeping with the results examined in the last chapter, and readily explained by the presence of a group factor (or factors) in that part of our data where mechanical problems were involved.

UNITARY NATURE OF m

(*a*) *Elementary School Data.* In view of the general size of the correlation coefficients we suggested, tentatively, that the super-correlation observed in the last chapter (as also, of course, the above-noticed specific correlations) was more probably due to a single group factor, or at most a few factors, rather than to a large number of independent factors. We may now put the matter to a crucial test by applying the criterion for a single common factor—the

[1] By Yule's theorem for partial correlation.

[2] I.e. correlation due to other factors than the general factor.

tetrad equation—to the specific correlation coefficients of Tables XXII and XXIV.

Confining our attention first to Table XXII, it will be seen that the M tests, here, include three tests of the same type, viz. M_5, M_6, M_7. In order to investigate the factors common to different types of test we have 'pooled' these three by averaging the coefficients relating to them (the first three rows of Table XXII). The resulting coefficients are given in the first row of Table XXIII, the remaining coefficients of this table being, of course, the same as those in Table XXII. In Table XXIII, then, with the exception of the coefficient in brackets (·56) we have the 'specific' inter-correlations of the four different-type tests with one another and with the school examinations.

If the tetrad-difference criterion be now applied to Table XXIII, the only differences of any appreciable magnitude which occur are the following:

$$(a)\ r_{E_3M} \cdot r_{CD} \sim r_{E_3D} \cdot r_{CM} = \cdot 25 \times \cdot 40 \sim \cdot 41 \times \cdot 49 = \cdot 1009$$
$$(b)\ r_{E_3M} \cdot r_{DC} \sim r_{E_3C} \cdot r_{DM} = \cdot 25 \times \cdot 40 \sim \cdot 45 \times \cdot 43 = \cdot 0935$$
$$(c)\ r_{E_3M} \cdot r_{MD} \sim r_{E_3D} \cdot r_{MM} = \cdot 25 \times \cdot 43 \sim \cdot 41 \times \cdot 56 = \cdot 1221$$
$$(d)\ r_{E_3M} \cdot r_{MC} \sim r_{E_3C} \cdot r_{MM} = \cdot 25 \times \cdot 49 \sim \cdot 45 \times \cdot 56 = \cdot 1295$$

Since their probable error is ·0355, none of these differences are large enough ($4\frac{1}{2}$ p.e.) to attach much importance to. In (*a*) and (*b*), however, the differences approach 3 p.e., and exceed this value in (*c*) and (*d*). They therefore suggest the possibility of additional small common factors. If so, these would seem to be located in E_3D in the case of (*a*) and (*c*), and in E_3C in the case of (*b*) and (*d*). We have already noticed a tendency in E_3 towards a somewhat lower reliability on account of the verbal mode of presenting the test, and the same in D possibly owing to the abstract nature of the diagrams.[1] Since E_3 and C also employed diagrams, though of a less involved kind, and C,

[1] See p. 98. Such tendencies, again, were merely *suggested* by the coefficients—hardly proved.

like E_3, was presented through the medium of written words, these common features in the mode of presentation may have caused some specific correlation between them. On the other hand, the tetrad-differences in (*c*) and (*d*) above are partly augmented by the somewhat higher correlation between the 'models' type of tests (r_{MM}). Since these were tests of the same type some small specific correlation between them seems not unlikely. This being so, the evidence for group factors common to E_3C and E_3D is still further weakened.

On the whole, then, there are little grounds for concluding other than a single factor running through the four different types of test to which the specific correlation observed in Table XXIII must be largely, if not entirely, attributed. Similar results follow from Table XXII.

(*b*) *R.A.F. 'Mechanical' Group*. Turning now to our next group of data—Table XXIV—and confining our attention to the four measurements which we have called the 'mechanical' group (rectangle A), the largest tetrad-difference to be found is ·0349, with a probable error of ·0204. Once again, then, there is no evidence of other than a single group factor in this part of the table.

(*c*) *R.A.F. 'subjects'*. If, on account of its specific correlation with the 'mechanical' group, the subjects of the Passing Out Examination (S) be included within it, the highest tetrad-difference becomes ·0602—a value less than thrice its p.e., ·0210.[1] Once more the 'specific' correlation is wholly accounted for by a single factor common to the 'mechanical' group and S.

[1] $r_{A_2E_3} \cdot r_{TS} - r_{A_2S} \cdot r_{E_3T} = \cdot 31 \times \cdot 40 - \cdot 22 \times \cdot 29 = \cdot 0602$. This might possibly suggest a small specific factor common to T and S: since these were respectively the theoretical and practical parts of the same examination, and consequently involved much of the same kind of technical knowledge, such specific correlation would not be altogether unexpected.

The p.e. given is that based on the average inter-correlation of all four 'mechanical' tests and S. It becomes ·0203 if we take, instead, the average of the four coefficients in the tetrad itself.

(*d*) *R.A.F. 'Intelligence' Tests.* Finally, we may examine the tetrad-differences of rectangle B in Table XXIV for evidence of factors common to members of the 'mechanical' and 'intelligence' groups. Here the small differences which occur are found to be without significance, for the largest, ·0182, only just exceeds twice its probable error, ·0081.

(*e*) *Conclusions.* To sum up our evidence with respect to the way in which *m* functions, the application of the tetrad-difference criterion to our specific correlation coefficients has failed to disclose the presence, here, of group factors. That is to say, when the influence of the general factor is removed the resulting specific correlation is adequately explained by a single factor running through those measurements in which this correlation occurs. Small factors common to certain of the M tests have been suggested, but the evidence for these is slender. Even if existent, such factors would seem to be accounted for by common features in the manner of presenting the tests, especially to younger subjects, rather than by factors within the mental processes essentially involved in working them. So far then as our present data are concerned, the marked super-correlation, and its natural consequence, the high specific correlations between those items in which the subject was required to deal with 'mechanical' material, is best explained by a unitary factor—*m*—running through this kind of work.

CORRELATION WITH *m*

Just as we were able to determine, from the ordinary inter-correlations of three tests involving a single common factor (*g*), the correlation of each of these tests with that common factor (Tables XX and XXI), so we may now employ the coefficients of specific correlation (Tables XXII and XXIV) to determine the correlations of the 'mechanical' tests with *m*.[1] This has been done, and the

[1] For method, see Appendix, p. 205.

correlations of the M tests taken by the elementary groups with *m* (working on Table XXII) will be found in Table XXV. Similar data for the mechanical tests taken by the R.A.F. mechanics are given in Table XXVI. These tables are, of course, analogous, with respect to *m*, to Tables XX and XXI, for while the latter indicate the extent to which each test is 'saturated' with the general factor which runs through all the data, so the present tables indicate the degree to which each of the mechanical tests is 'saturated' with the group factor.

Each of the M tests correlates fairly highly with *m*. The average for the six tests employed with the elementary groups is ·66; that for the two tests given to the R.A.F. mechanics is ·61. The two parts of the Passing Out Examination ('Trade Knowledge' and 'Subjects') involve *m* to about the same extent, ·58 and ·59 respectively. While these coefficients are not sufficiently high to permit our using, safely, any single test as a measure of *m*, the tests compare favourably, in this respect, with many of the tests of 'intelligence' in current use. Thus, to take a notable example—the Thorndike Intelligence Examination used at Columbia College—the correlation of this test with *g*, as determined from its correlation with the special criteria which have been selected to establish its validity, proves to be ·51.[1] Similarly, the average correlation between the following 'intelligence' tests,—viz. 'analogies', 'completion' 'directions' and 'memory for digits', and *g*—was found to be ·615;[2] while Webb, working with 'corrected' coefficients,[3] found his five tests ('reasoning', 'comparison', 'problematic situations',

[1] The criteria were (1) Scholarship score during Freshman year. (2) Regent's Examination score and (3) Secondary School Records, The coefficient given above was calculated from the data of Table 32, p. 87, *Measurement in Higher Education*, B. D. Wood.

[2] By Spearman, from data obtained by Otis and Carothers: see *Abilities of Man*, p. 219.

[3] I.e. corrected for 'attenuation' due to errors other than the 'sampling' error. Such correction tends to raise the coefficients.

'definitions', 'opposites') to correlate with g to the average extent of ·65. Such tests appear to be among the best commonly used to measure 'intelligence'.

Table XXVI provides an interesting comparison between the two parts of the R.A.F. Passing Out Examination. The 'subjects' part of this technical examination is seen to involve as much m as the test in trade knowledge and ability. Reference to their correlations with g (Table XXI) shows that the former ('subjects') part is saturated with g and m to about equal extents, while the trade test is more saturated with m than with g. This suggests that an individual endowed with a fair degree of m may make a good practical 'mechanic', yet never reach the higher professional walks, entailing deeper theoretical knowledge, through lack of g.

MEASUREMENT OF m

(*a*) *Method of Measurement*. We now have, for the first time, the necessary data for measuring a 'special ability'—m, and for checking the accuracy of this measurement. To consider first the method of obtaining the measurement, let us denote the score of an individual, x, at one of the M tests, a, by Max. It would be clearly erroneous to assign to him the whole score Max as his measure of m, since this score depends not only on m but also on g, and possibly on factors which may enter 'specifically' into the particular test a. On this account the score must be resolved into three parts, one part being a function of his g, another a function of his m, and a third a function of his 'specific' ability for test a.[1] Prof. Spearman has shown that the first of these parts is equal to $r_{ag} \cdot g_x$, where r_{ag} is the correlation of a with g, and g_x is the amount of the individual's g, whence it follows that g_x

[1] When there is no specific factor the third part becomes zero. While this is hardly likely to occur in any single test, the effects of such specific factors will tend to cancel in a team of M tests.

equals $r_{ag}.M_{ax}$.[1] Analogously, the second of these parts equals $r_{am}.m_x$, where r_{am} is the correlation of test a with the group factor m, and m_x is the amount of the individual's m; whence the required determination of m_x is given by $r_{am}.M_{ax}$, where m_x and M_{ax} have the same standard deviation. Thus the value to be assigned to m_x is obtained by multiplying x's score at the test by the correlation of that test with m. For example, ·68 of the score made at M_5 (Table XXV), ·65 of the score at M_6, etc., gives the most accurate measurement of the individual's m as gauged by these tests. The customary practice of taking the whole score as the measure of the 'ability' involved would introduce an error of over 40 per cent. on this account alone!

(*b*) *Accuracy of Measurement.* Even the more accurate determination, $r_{am}.M_{ax}$, involves a probable error amounting to $\cdot 6745\sigma_a (1 - r^2_{am})^{\frac{1}{2}}$, where σ_a is the standard deviation of a. It obviously decreases as r_{am} increases, and unless r_{am} is high the probable error will be so large as to render our measurement untrustworthy. To take an actual case, the root quantity above works out to ·89 for the M test having least correlation with m, viz. E_3 (·46). This means that the sampling error involved in employing this test alone as a measure of m is as large as 89 per cent. of that expected from a pure guess. For M_7, which correlates ·79 with m, the figure falls to ·61, so that a measurement of m effected by this test is appreciably more accurate than that given by E_3; yet it is not satisfactory, since the probable error is still no less than 61 per cent. of that likely to arise from mere guesswork. In order to arrive at a more accurate determination we must somehow raise the correlation between the measuring instrument and m. This can be done by using not one, but a number of M tests, and 'pooling' the scores. For example, if we pool the two tests which correlate most with m, namely M_7 and

[1] Provided gx and M_{ax} have the same standard deviation. See *Abilities of Man*, p. xiv ff.

C, and give equal weight to each, the correlation of this 'team' with m becomes ·85 [1]; if, further, we include Test D, the correlation of our team with m becomes ·87. By adding yet a fourth test—another of the completion type—the correlation of the team with m is raised to ·904.[2] While the standard of accuracy indicated by this figure would seem to be superior to that commonly attained in much current mental testing, it still leaves something to be desired, for we should hardly remain satisfied with a correlation under ·95. This standard can be reached in the present case by still further increasing the number of tests in the team, and by giving additional weight to some of them. One such team is composed of the three 'models' tests (M_5, M_6, M_7), the diagrams test (D), and five completion tests (similar to C). The correlation of this team with m is ·951.[2] A yet higher correlation with m may be looked for from improvements in the tests suggested by the analysis to which we now turn.

[1] By Spearman's formula for the correlation of sums, *Brit. Jour. of Psych.*, v, 417.

[2] Assuming that the average correlation of the new C test(s) with the others in the team is the same as that of the present C.

CHAPTER IX

SUBJECTIVE ANALYSIS OF *m*

METHOD ADOPTED

TO obtain insight into the psychological nature of the group factor which the correlations have disclosed, a variety of our tests were submitted to psychologists well known on account of their special qualitative studies of mind, and in other ways, as able introspectors. Their careful accounts of what occurred mentally during the working of each test were taken down. Introspective data were also collected by ourselves during the construction of the tests, and subsequently. In our own case we found it helpful to adopt, in addition, a somewhat novel method of recording the introspection. This consisted in noting down as briefly as possible each thought (or other process) as it occurred while the task of solving the problem was actually in progress. While this procedure necessarily lengthened the time taken to solve the problem, and may at times have altered, to some extent, the course which mental activity would otherwise have taken, it served to record facts which the ordinary retrospective method might have overlooked. On this work of analysis much light was shed by Professor Spearman's principles.

In the light of these introspections the mental activity involved was analysed into its constituent unit-processes, special regard being paid to those processes which seemed most directly associated with the 'mechanical' factor.

Here, as throughout, we have been concerned with perceiving and thinking rather than with feeling and willing, i.e. with 'cognition' rather than with 'affection' or 'volition'. Consequently, our attention has been given mainly to cognitive processes which occur in solving the tests. It is realized that emotional and volitional factors are important determinants of success in any task, but these would seem to merit a special study. The analysis has been based on Professor Spearman's *Principles*. In the hope of making it clearer to those who may be unacquainted with these, we preface it by the following brief account of the three principles with which we shall be chiefly concerned.[1]

THREE FUNDAMENTAL PRINCIPLES

First Principle: Apprehension of Experience

'Any lived experience tends to evoke immediately a knowing of its character and experiencer.' The first principle, thus stated, maintains that in the case of any cognizable item that comes within range of our experience, we tend to know immediately, i.e. without the occurrence of intermediate conscious processes, one or more of its 'characters', and ourselves as knowing this 'character'. To this process of knowing the 'characters' of items given in experience Professor Spearman has given the name 'experiential apprehension', or more briefly 'apprehension'.

For example, the subject looks at a working mechanical model. The various parts of the model are the items of experience; their *shapes, sizes, movements*, etc., are their 'characters'. The subject will tend to know (apprehend) these characters when he looks at the items, and in so far as such knowledge occurs it does so without

[1] For a full account, see *The Nature of 'Intelligence' and the Principles of Cognition*, C. Spearman (Macmillan, 1923).

the intervention of other processes—it is a unit-process incapable of further introspective analysis. By this same principle, too, he tends to know, in the same immediate way, that he knows these characters.

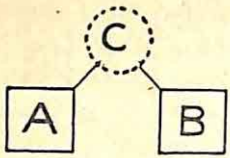
SECOND PRINCIPLE: EDUCTION OF RELATIONS

Statement. 'The mentally presenting of two or more characters (simple or complex) tends to evoke immediately a knowing of relation between them.' Starting with the products of the first principle—characters—this second principle states that when two (or more) characters (such as '*black*' and '*white*') are presented mentally, there tends to occur an immediate knowing of one or more relations between them (such as '*opposite*'). Such cognizing of relations is known as 'eduction', to distinguish it from the 'apprehension' involved in the first principle.

'*Fundaments.*' The items that bear a relation to each other are known as its fundaments. Thus, in the above example, 'black' and 'white' are the fundaments of the relation 'opposite'. It is clear that relations may be educed between any of the characters apprehended in experience, and also between the relations themselves, as when the relation which three bears to six is seen to be equal to that which five bears to ten. Consequently, any of the products of the first and second principles (and also of the third, as we see later) may serve as fundaments, and these may vary considerably in degree of complexity and abstraction.

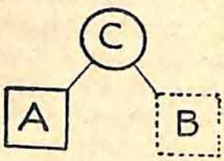
Diagrammatic Representation. The eduction of relations is conveniently represented symbolically by the following diagram in which the squares represent the apprehended fundaments, while the dotted circle represents the relation which tends to be educed between them.[1]

[1] From Spearman's *Principles*, p. 64.



THIRD PRINCIPLE: EDUCTION OF CORRELATES

Statement. 'The presenting of any character together with any relation tends to evoke immediately a knowing of the correlative character.' The process covered by this third principle may be described as follows. When any character such as '*white*', together with any relation such as '*opposite*', is given initially, then it is possible to educe directly from these items a second character which bears that relation to the given character (in this instance, '*black*'). This second character is known as a 'correlate'. The knowledge of the appropriate correlate has its immediate source in, and is, as it were, 'drawn out' from the very meaning of the initially presented items. The process of 'correlate finding', then, like that of 'relation finding', is eductive. It, too, may be represented diagrammatically.[1]



Here, A represents the initially given character which is serving as fundament, and C the initially given relation; B represents the correlate educed from A and C.

As before, the fundaments may be simple and concrete, or may attain to any degree of complexity or abstraction: they may, moreover, be relations, as when the *opposite* to '*different*' is seen to be '*same*'.

[1] Spearman's *Principles*, p. 92.

Multiplicity of Elements. So far, only cases in which relations have functioned singly have been considered, but in the manifestations of both the second and third principles the fundaments or relations which enter into any single eductive process may be multiple, as when each of a number of objects is seen to be different from, or similar to, the rest (second principle), or when a point equidistant from three given points is found (third principle).

THE ANALYSIS OF *m*

Introductory. All the essential processes associated with the group factor (*m*) come clearly and completely to view in the 'models' tests. We shall therefore employ our analysis of the latter to provide typical examples of these processes, and accord briefer treatment, in the Appendix, to the other tests in which *m* was found.

It will be remembered that in the 'models' test the experimenter moves one of the visible parts of the mechanism, and then there ensues a movement of one or more other parts. The subject is required to indicate the mechanism needed to fill the gap(s) between the original and the ensuing occurrences. In its general form, then, this test is not unlike the Ebbinghaus Completion Test,[1] but differs from it entirely in material. The activity involved in solving each 'model' falls into three stages, viz. (1) the specific formulation of the problem, (2) the devising of some general method for solving the problem, and (3) the working out of the details of this method in relation to the problem. The time and effort needed for these stages was not the same in each test. In some cases the finding of the method and its correct detailed application to the problem in question occurred almost simultaneously, so that it was difficult to distinguish, introspectively, the second stage from the third. In other

[1] An 'intelligence' test in which certain missing words have to be inserted in a sentence.

cases, particularly where the mechanisms were more complex, the third stage was easily distinguishable from the second, and became the crucial part of the whole problem. Let us examine these stages in detail.

First Stage: Specific Formulation of the Problem

Description. Here the subject must follow the demonstration of the model, and note the various parts pointed out by the experimenter. In particular he must observe what the experimenter does when he works the model, and what results therefrom. He has passed successfully through this stage when he has formulated the problem in some such words as, 'How can that button be moved up by moving this handle down?'

Although the unit-processes involved in this stage are numerous, it must be remembered that more than three moving items are seldom introduced into any one 'model'. Moreover this work is facilitated by the experimenter, who not only demonstrates the actual movements by working the model, but also directs attention to those features which enter essentially into the problem. Consequently, the work of this first stage, in so far as it refers to the grasping of the general problem as initially presented, seemed well within the capacity of all subjects.

But the subject must not only make clear the requirements initially, he must keep them clear during the second and third stages. Here greater individual differences were observed. This is not merely a matter of memory. A weak subject who finds his whole attention engrossed over one baffling point is apt to lose sight of some other essential requirement. To quote the introspection of a subject who had incorrectly placed a pulley to the right of, instead of above, a certain groove:—'I placed top pulley to the right without thinking of its position. It seemed to be swamped in the larger problem of how the downward pull of the string would move the button upward.'

Finally, the making of the requirements clear includes

the analysing of the initial, complex problem into its subsidiary constituent problems. The importance of such analysing is shown in the following introspection: 'The idea occurred to me that there might be two bars . . . but as it (the model) worked again I thought this impossible or unlikely. I then thought that the stopping (of the bar) could be produced by a projection fixed to the bar. The method of stopping the bar seemed to be the main problem. I did not know where the projection was placed. . . . I thought there might be several projections, but had no idea of their precise situations or the effects they would produce. I then split up the problem into two parts and asked (1) what would prevent the bar moving more than half way to the right, and (2) what would prevent movement of the bar to the left to the extent observed. I decided that the projection as indicated (in S's answer) would do this. The real intellectual work begins with splitting the problem into two parts.'

The essential cognitive processes involved in this first stage may be divided into :—(1) those involved in cognizing the presented items when stationary, and (2) those involved in cognizing the movements of those items which move. They may be stated as follows :—

Processes involved in cognizing the items when stationary:

(1) Apprehension of certain spacial characters of each item, viz. its shape, size, and position.

(2) Apprehension of certain simple qualitative characters of each item, especially whether it is 'stiff' (as a rod) or 'limp' (as a string).

(3) Eduction of the relations in space which the position of each item (at any given moment) bears to the positions of the other items (at the same moment).

Processes involved in cognizing the items when moving:

(1) Apprehension of certain characters of the movement of each item, viz. its spacial characters of shape, size (or extent), position, and direction; its space-time character of speed; its temporal

character of time of occurrence (simply apprehended as occurring 'now', or 'just occurred', or 'about to occur').

(2) Eduction of certain relations between the above characters of the movements, viz. the relation of likeness (or difference) between their shapes, simple quantitative relations between their sizes, the spacial relations between their positions (both between the positions of the completed movements, and between the positions which the moving items may at any time occupy during movement); the spacial relations between their directions; simple time relations (as of 'simultaneity' or 'succession') between their times; simple quantitative relations between their speeds (such as 'greater', 'equal', or 'less').

(3) Eduction of remote causal relations between the movements themselves.

With regard to the last-mentioned causal relations, if A, B and C are three items such that when movement is imparted to A, B and C are also observed to move, A's movement will be cognized as the cause of B's and C's movements, but it will not be known immediately from these observed movements whether the movement passes along the hidden part of the mechanism from A to B and thence to C, or from A and C and thence to B, or directly from A to both B and C. Hence although the movements are known to be causally related, the precise way in which they are so related (i.e. the relative immediacy of the relation in the case of any pair as compared with any other pair) is not given in the presentation.

The knowledge that the observed movements are causally related is derivable from three sources: (1) by simple acceptance of the experimenter's statement that the observed parts of the mechanism 'work together'; (2) by reproductive association—the subject, having observed formerly that the movement imparted to one part of a

mechanism is able to cause movement in other distant parts by means of suitable connections, and that such movements cannot occur of their own accord, now associates by similarity the present mechanism with such known mechanisms; (3) by eduction the movements of one item are seen to vary concomitantly with those of another, from which is educed their causal relation as an attribute of the movements themselves.

Diagrammatic Representation. The mental processes of this first stage are represented diagrammatically in Fig. 5: the characters by black squares, the relations by black circles. The dotted rectangle represents the gap which the subject is called upon to fill, and encloses the items which must be cognized in stages II and III, and whose nature will be dealt with later.

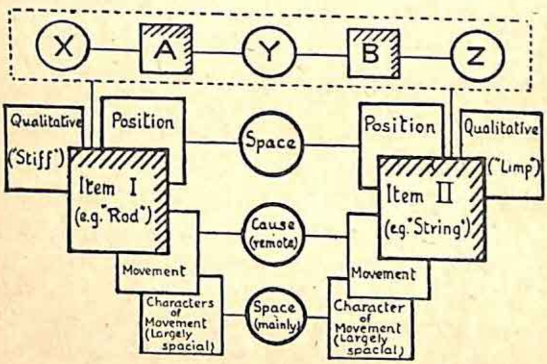


FIG. 5.

Comments. The work of 'making the requirements clear' consists essentially in selecting from the various characters and relations given in the presentation those which bear specifically on the problem, and bringing these to clear awareness. Thus, where a downward movement of one item must be brought about by an upward movement of another, attention must be specially focused on these particular characters of the movements and on the relations

between them in order to make this requirement clear. Similarly, the work of analysing the problem into its parts consists in singling out for special consideration each requirement in turn and making this clear.

We shall see later that many of the items cognized in this stage function in the eductive processes of the second and third stages. The subject, however, may not always be fully aware of the items which function, for these may do so at a very low level of intensity, or even sub-consciously.

Terminology. For clearness and brevity, we shall refer to the 'characters' enunciated above as mechanical characters—and to the relations as mechanical relations. Of such characters (or relations) those which bear specially on the problem in question we shall call the relevant mechanical characters (or relations).

Second Stage: Finding a General Method

Description. Having made the requirements of the test (or some particular part of it) clear, the subject proceeds to find some method which will satisfy these requirements, i.e. to fill in by a suitable mechanism the gap between the presented items, represented by the dotted rectangle in Fig. 5. If he does not see immediately how this is to be done—and this seldom happens except in the case of the first model of each series, which was made especially easy—he tends to conceive, in quite general terms, a method which seems likely, or possible. The details are usually lacking. There may be, for example, no clear idea where the pulley, or the pivot, or the string which it is intended to use should be placed. That is to say there is, as yet, no clear cognition of the relevant mechanical characters of the items to be employed. As these become known the work passes from the second stage to the third.

Two Methods of Search. The search for a suitable method may be pursued in either of the following ways:

(1) *Reproduction followed by Eduction.* The presented mechanism recalls some particular kind (or class) of mechanisms known to the subject (sometimes a mechanical model which he has previously solved), and he thereupon reproduces such items as he has learnt to associate with these mechanisms.

If reproduced from a general class of mechanisms the items are usually vaguely conceived. The subject must then re-examine the specific requirements of the test in order to give clearer definition to those characters of the reproduced items which bear directly on the problem. In so far as this occurs the process is eductive. Such characters of, and relations between, the presented items relevant to the problem (i.e. the 'requirements') are the first fundament, the causal and spacial relations which it is proposed that the reproduced items should bear to these act as the mediating 'relation', the more clearly defined characters of the reproduced items are educed as the correlate.

When derived from some definitely remembered 'method' the characters of the reproduced items are usually recalled with greater clearness. Reference to the requirements of the test is then necessary to determine whether these characters are suitable. Here, again, the process is one of eduction—but this time of relations—in which is sought the relations between the characters of the items as reproduced and the 'requirements' as presented in the test. Such eductive processes lead either to the acceptance or the rejection of the 'method'. If the method is found unsuitable, the subject must renew his search. As the search proceeds the items reproduced tend more and more to be controlled by such knowledge of the special requirements of the problem as has come to light during previous trials. That is to say, this 'trial and error' method tends to pass into an alternative method which we will now proceed to describe.

(2) *Eduction followed by Reproduction.* This alternative

method is by means of correlate-eduction followed by reproduction. One or more of the attributes of the presented items, i.e. the 'characters' and 'relations' of the items, and of their movements, cognized in Stage I, function as the initially given fundament; the relations which the items sought for in the method must bear to these presented items are given in the problem itself, and function either singly or complexly as the given 'relation', hence are educed one or more attributes (i.e. 'characters' or 'relations') of the item sought for. The item which is known to have such educed characters then comes by reproduction.

For example, the subject educes that something 'stiff', 'joining two buttons in a straight line', which can also 'move with the buttons' in a certain observed way, is required, and reproduces a 'rod'; or he educes that something is required that will 'pull' but not 'push', and reproduces 'string'; or again, he educes that in order to connect up certain items the required item must pass, as it were, round corners, and reproduces 'pulleys and string'.

Chief among the educing fundaments are the space relations between the presented items and their movements. These differ peculiarly from other kinds of relation in that they have, themselves, a spacial character. Thus the complex space relation between three co-linear points has a definite spacial character differing from that of the space relation between any other arrangement of points. Similarly, the relations between the movements of the various items have each a spacial character. The subject knows that the items (and their movements) sought for in the method must fit in spacially with those given in the presentation: that is to say, that their spacial characters must in some respects resemble those of the space relations between the presented items. Hence is educed the correlative spacial character of the items sought for. To give an illustration, a subject (a university graduate) was

shown a 'model' in which two buttons moved along grooves at right angles to one another. He stated that this arrangement of the movements (i.e. the spacial character of their relations) was seen to differ from a previous one (in which the movements were parallel) by being more complex; it seemed divisible into two parts. Consequently he sought for something having two parts similarly arranged. This suggested the two arms of the human body—then two rods pivoted together at one end. He remembered having seen a similar arrangement of rods in a strength-testing machine. Here the particular spacial character of the relation between the presented movements, together with the relation of 'resemblance', enabled the correlative character of the required item to be educed—the actual item then coming by reproduction.

Diagrammatic Representation. The processes whereby certain of the characters of the items sought for in the 'method' tend to be evoked, may be represented diagrammatically:

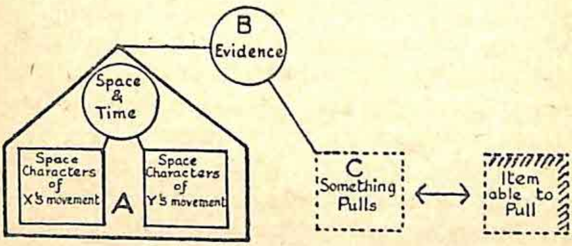


FIG. 6.

A represents the initially given (complex) fundament.
B represents the initially given relation.
C represents the educed correlate.
D represents the reproduced item, i.e. something that can 'pull' (or 'push', or do both, as the case may be).
↔ reproductive association.

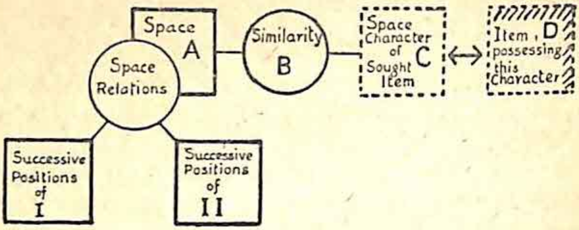


FIG. 7.

A represents the educing fundament, viz. some common spacial character of the initially given relations.
B represents the educing relation—the item sought for is known to 'fit in' with A.
C represents the educed correlate.
D represents the reproduced item.
↔ reproductive association.

Comparison between the two Methods. Both methods involve reproduction and eduction, but differ in the order in which these occur. By the first method the items sought for come by reproduction and must then be compared with the requirements of the test to determine their general suitability; by the second method the general character of the items sought for is educed as a correlate to the given requirements, and the item having this general character is then reproduced. Similar differences are to be observed between the methods of solving an 'analogies' test, or a 'completion' test, or indeed, it would seem, any test in which some missing essential part has to be found. To take an example from 'analogies', the subject is presented mentally with the following :—'Before, behind; future, ?' in which he is required to find a fourth term bearing the same relation to the third as the second bears to the first. He may proceed in either of two ways. He may first reproduce by mere association of ideas the term 'past', and then see whether this term fulfils the required condition—a procedure which corresponds to

our first method above. Or he may first educe the relation between the first two terms and then, using this as the educing 'relation', and 'future' as the initial fundament, educe the required correlate—a procedure corresponding to our second method above. It is clear that of these two methods the second is to be preferred, since the search when thus pursued is directed by some knowledge of what to look for. If, however, the eductive process is weak, so that the subject finds it difficult to cognize clearly the relation between the first two terms, he must needs resort to the first method. By so doing he tends to lighten the demand made upon his eductive powers, for now he has only to educe the identity (or otherwise) of the two relations—a task usually easier than that of educing their precise character.

And so with our 'models'. The weak subject tended to adopt the first method. He would frequently attempt to bring the requirements of the problem under some familiar general heading or principle, such as that of 'levers or 'pulleys', or would recall some previous attempt—often with little bearing on the problem in hand. His eductive powers for this kind of test being weak, the third stage—that of 'applying the method'—was usually poorly carried out and he seldom arrived at a neat solution.

But a 'model' differs from an 'analogy' in one important respect—the items required to be found in the former number not one, but several, and the relations to be satisfied are many. In this way it more closely resembles a 'completion' test in which several words, or even a whole sentence, are missing. On this account the items are seldom reproduced with full knowledge of all their essential 'mechanical' relations and characters. To bring these to greater clearness and perfection is the work of the eductive processes of the third stage.

Third Stage: Working out and Testing the General Method

Description. During this third stage the subject endeavours to fill in the actual details of the gap represented by the dotted rectangle in Fig. 5. This work may be divided broadly into two parts, viz. (A) the detailed application of the general method decided upon in the previous stage to the particular 'model' in question, and (B) the testing (mentally) of the 'method' when applied, to see whether the 'model' as completed will work. The latter part may be dispensed with when the task is an easy one; otherwise, it forms an important final step.

A. *Detailed Application of the 'Method'*

The mental work, here, consists essentially in cognizing clearly those attributes of the various items it is proposed to employ in the 'method' which we have called their relevant mechanical characters. This includes, of course, the modification or elimination of any characters that may have been wrongly attributed to these items. He must also cognize those relations (mainly spacial) which the character(s) (such as shape and position) of each item must bear to those of other items. Especially important here are the spacial relations between the movements of the items, and particularly so in the case of each pair of contiguous items.

The eductive processes involved in this part of the work are largely those of correlate-finding. For example, the subject, having decided to connect two items by a rod, wishes to determine where the pivot should be placed. Several fundaments and relations are available whence this knowledge may be educed. The successive positions (or any two positions) which the rod is required to occupy when moving may function as the initial fundament, the knowledge that the pivot must be at some point common to all these rod positions provides the given relation; hence is educed the position of the pivot, viz. the point

of intersection of these rod positions. Alternatively, the quantitative relation between the sizes of the arcs described by the two ends of the rod is first observed; the position of the pivot is then educed as that point which divides the rod into two parts bearing this quantitative relation to one another.

In the last example, the relation mediating between the two fundaments ('pivot' and 'rod') must itself first be educed as the relation between two other fundaments (the movements on the ends of the rod). Sometimes such educed relations will form part of the initial fundament, particularly when the mediating relation is either a causal or an evidential one. The following is a case in point:

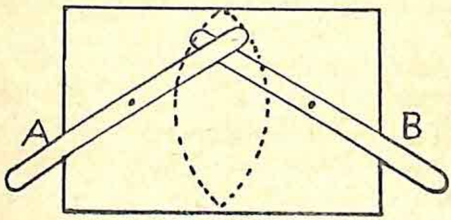


FIG. 8.

A and B (Fig. 8) are rods so connected that when A is pushed upwards B also moves upwards; and vice versa, when A is moved back into its original position, B simultaneously moves back. The subject decides to produce A and B towards one another until they meet, and to fix each rod to the card by a pivot. It is then seen that the contiguous ends of the rod would describe circular movements. The space relation between these circular movements is educed as that of 'overlapping'. This relation, together with the 'shape' of the movements, functions as the initial fundament, the mediating relation is that of 'evidence'; hence is educed the need of some modification at the ends of the rods to permit of this 'overlapping'.

The precise kind of modification which the subject may employ must be decided by further eduction, or by reproduction. The following figures show how the subsequent course of eduction may lead to two different kinds of modification :

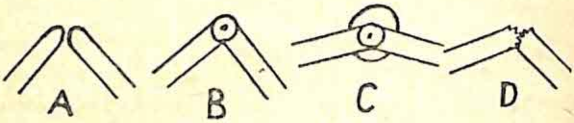


FIG. 9.

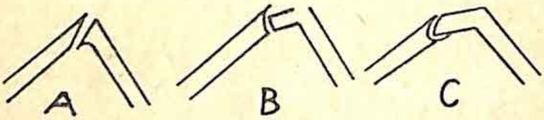


FIG. 10.

In Fig. 9, A, B, C and D illustrate a subject's successive attempts to devise the necessary modification of the ends of the rods. Fig. 10 shows the same thing for another subject. In both cases the subjects (university graduates) grope their way to a partial solution of the problem by a series of eductions in which the necessary spacial characters of the end of the rods become gradually clearer. Some further examples illustrating the eductive work of this third stage will be found in the Appendix.

B. *Testing the Method*

Difficulty Experienced. The second part of this stage—the final testing of the method—consists in cognizing whether, and if so, how, the various items which have been introduced into the solution will move when an attempt is made to work the model. References to it were made in the introspections by such words as : 'I tried to cognize the effect of moving the handle', 'I tried to see how it would work', 'I put in the pivot and saw that it would

work'. It becomes more evident as a distinct step where the subject has had difficulty in applying the method. In such cases he is usually unable to deal with more than a limited part of the problem at a time. Having completed the 'model' in this piecemeal fashion, it remains a distinct task for him to see whether all the requirements are satisfied.

The solution referred to in Fig. 14[1] brings out this step clearly. The subject (a university graduate) first obtained string C, then, after a distinct pause, string D. He then tried to see how the complete arrangement would work. This appeared in the introspection because the subject had the greatest difficulty in doing so; in his own words, 'I then tried the movement (mentally) again to see the combined effect of both strings. I found it difficult to cognize this combined effect and was not satisfied with the result, but had to leave it.'

Two Classes of Items. The nature of this difficulty will be rendered more intelligible if we begin by classifying the items employed. These may be divided into two classes, viz. those, like rods, strings and springs, which are used to transfer force from one item to another; and those, such as pulleys, pivots and pins, whose function it is to determine the spacial characters of the movements which may arise in items of the former class as the result of such force. Whereas members of the former class may form links in a chain along which motion is transferred, the latter do not, but are, as it were, 'bound' to those links whose movements they determine—the pulley to its string, the pivot to its rod. The 'links' may be further divided into two classes, viz. (1) those, like rods and strings, which retain their shapes and sizes throughout, and (2) those, like springs and elastic bands, which are used on account of their elasticity.

Modes of Linkage. The 'linked' items may be further distinguished according to their mode of linkage. They

[1] Appendix, p. 200.

may be fastened together, or may be simply contiguous in space. The mode of fastening may allow some freedom of movement at the joint, which may be rotary, as when one rod pivots on another, or translatory as when it travels along a slot cut in the other. Items may be employed as 'simple' links, or combined together into 'compound' links. Fig. 16[1] will illustrate this. When X is pushed upwards its movement is transferred to B and C by the single 'link' A; such a link will be referred to as a simple link. A's movement, on the other hand, is transferred to Y by means of two items, B and C, linked not only to A but also to one another: such a link as B–C, consisting of two or more linked items, will be referred to as a 'compound' link.

Two or more links (simple or compound) may be put together to form a 'chain'. A pair of items may be connected by a single 'chain', as XY in Fig. 16, or by a double chain, as AB in Fig. 13.[2] Chains of greater complexity were not employed in our tests.

General Course of Mental Activity. Now the mental work involved in the present phase, that of testing the method, consists, broadly, in taking each pair of links in turn and considering four things: (1) the kind of movement which the force imparted to the 'operating' link tends to bring about in it; (2) the spacial characters ('position' and 'direction') of the force which is consequently transferred to the 'operated' link; (3) the kind of movement which such force tends to impart to this link; and (4) the possibility of movement actually occurring, and if so, the kind of movement which does in fact occur. Of these, the first three, although essential preliminary steps, usually provide far less difficulty than the fourth, which is the principal step here. We will consider the mental processes underlying these steps in the case of the pair of simple links shown in Fig. 11.

Here the string S, passing over two pulleys P_1, P_2, has its

[1] Appendix, p. 201 [2] Appendix, p. 199.

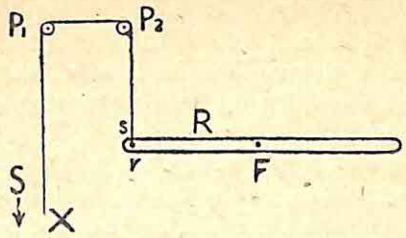


FIG. 11.

end *s* tied to the end *r* of a rod R. The latter is pivoted to a support at F. P_1, P_2 and F are in the same vertical plane. It is required to cognize how the string S and the rod R will move when S is pulled at X in the direction of the arrow. Such a simple task would be immediately carried out by most subjects—although even here some striking differences were observed.

Preliminary Steps. The first step consists in recognizing the kind of movement which the pull at X tends to set up in the string, which is here the operating link, and, in particular, the direction of the movement at *s*. Such knowledge is given by the space relations between the point X at which this force is applied and the items to which the string is 'bound', viz. the pulleys P_1, P_2, together with reproductive knowledge of how strings in general act when pulled.

The question to be answered in order to carry out the second step may be put quite generally as follows: (*a*) Will the 'operating' item exert a force on the 'operated' item when the former tends to move in the way cognized in the first step? (*b*) If so, at what point in its movement will it begin to exert this force? (*c*) At what point on the 'operated' item will it be exerted? and (*d*) in what direction?

Where, as in the present case, the two links are in immediate contact, the answers to these questions come by way of reproductive knowledge that a string tied to an object

will exert a pull as soon as it is itself pulled taut, at the point to which it is tied, and in the direction in which the tied end tends to move. In the light of this knowledge, *s* is cognized as tending to pull *r* 'upwards' when the string is pulled.

The kind of movement which tends to be set up in R as the result of the pull at *r* must now be cognized, such work constituting the third step. This is merely a repetition of the first step, but now carried out with respect to the 'operated' item R. As before, the answer is known from the space relation between the point of application of the force (*r*) and the pivot (*f*) to which the rod is 'bound', together with simple reproductive knowledge of how rods rotate on pivots. In this way R is cognized as tending to rotate in a clockwise direction as a result of the pull at *r*.

Principal Step. So far only one position of the 'links' has been considered, viz. that which they occupy before movement begins. Usually, however, the two items are required to move in such a way that they continually change their positions relative to one another, with a consequent change in the direction, and perhaps also position, of the force on the 'operated' item. Usually, too, the 'operating' item is required to exert a continuous force on the 'operated' item during such part of its own movement as will serve to bring about a definite kind of movement in the 'operated' item. It therefore remains, in this fourth and principal step, to determine whether the two items are so 'linked' that the requisite changes in their relative positions may be possible. To put this question in reference to our example,—how precisely will the rod and string so tied together move, if at all, when the string is pulled? This step was referred to as 'cognizing the combined effect of the movement'.

There are two ways in which the subject may carry this out. He may cognize the movements of both items simultaneously as they are conceived to travel from their initial

to their final positions;[1] or he may consider each movement separately. The essential underlying process, however, is the same in both cases, viz. that of correlate-finding.

To take the first case, the rod is conceived to move forward slightly in the way cognized in step (3). We will call the position into which it immediately passes R_2 (Fig. 12). The correlative position of its end r is known from the constant relation which it bears to the rod. Let this position be r_2. The reproductive knowledge that the end s of the string must remain tied to the rod gives the relation between s and r, whence the correlative position of s (say s_2) is educed. Finally, from s_2 and the known space relation which the rest of the string must bear to its end which passes over the pulleys as cognized in step (1), is educed the correlative position of the whole string (S_2). In the same way, as the rod is conceived to continue its movement forward through R_3, R_4, etc., the correlative positions which must be taken up by the string are educed. The space relation between each pair of correlative positions at any point of the movement indicates the kind of pull on the rod at this point, and hence it is known whether there will be any tendency to further movements. Such further movement of the rod will be cognized as 'possible' so long as the correlative position of the string is one into which the pulleys will allow it to be pulled, as cognized in step (1).

These processes are symbolized in Fig. 12, where R_1, R_2, R_3 . . . R_n symbolize the course of the rod's movement, S_1, S_2, . . . S_n, the educed correlative movement of the string. The small circles symbolize the space relations whence, from any given position (R_2) of rod, the cor-

[1] Some subjects had the greatest difficulty in cognizing movements of two objects simultaneously. One subject (an eminent psychologist) found that only at the highest pitch of concentrated attention could he 'catch a glimpse' of two wheels of different sizes revolving simultaneously around the same axle; he had equal difficulty in dealing with a driving band passing around the circumference of a pulley wheel.

relative position (S_2) of string is educible. The large circles indicate the space relation whence it is known whether any further movement will tend to occur. The thick black squares represent the originally given fundaments.

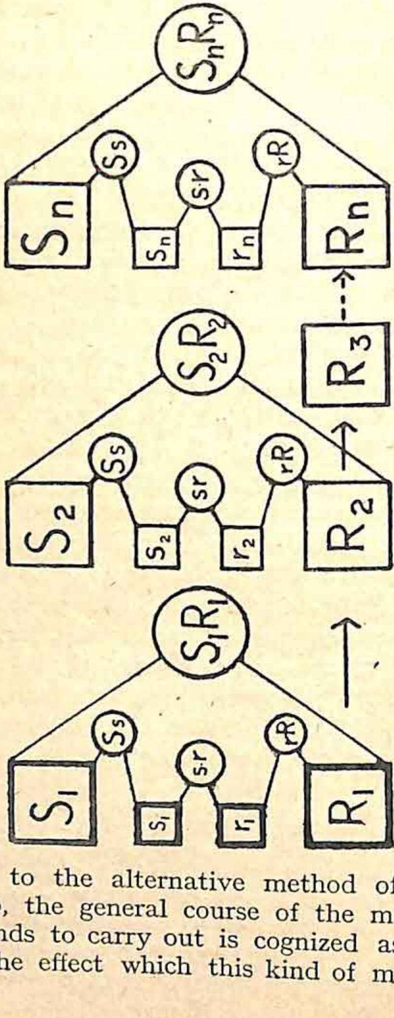


FIG. 12.

To turn to the alternative method of effecting this fourth step, the general course of the movement which the rod tends to carry out is cognized as before—steps (1)–(3). The effect which this kind of movement would

have on the item to which it is 'linked' is then considered in the light of simple reproductive knowledge [1]—in the present case, for example, it is seen that the clockwise movement of the end of the rod would pull the end of the string in the same direction.

The movement will be cognized as 'possible' so long as this clockwise movement of the end of the string is consistent with the movement of the string over the pulleys as cognized in step (1). The position in which the items come to rest (S_nR_n) is cognized as that point in their course at which this condition ceases to be fulfilled, i.e. at that point in the movement of the rod at which its end approaches nearest to pulley P_2. The extent of the whole movement of either item is then known, being the space traversed in passing from its initial to its final position.

General Survey. Having worked over every case of direct linkage, it remains to survey the mechanism as a whole to see that no item in moving will interfere with the movement of any other. Where, as in our tests, the mechanism is not too complex and the links are fairly widely spaced, a general glance will usually suffice for this. Where, however, the close proximity of any pair of links suggests the likelihood of one interfering with the other, the correlative positions which each of the pair of items concerned will pass through as they move, must be cognized; whence it can be seen whether or not the items will tend to occupy, simultaneously, the same position at any time. The finding of these correlative positions, although a more complex operation than that which we have just considered, involves no essentially new process. For any given position of one 'link', the correlative position of any other 'link' of the chain may be found by cognizing, successively, the correlative positions of the

[1] Such knowledge relates to the way in which the items are 'linked'; objects pinned or tied together are known to remain in contact when moved, rods slotted together may slide on one another to some extent, etc.

intervening links. It would seem, however, that the greater the number of links one can deal with at a time, by keeping all the necessary relations in mind, the better.

Where more than one 'chain' is employed, what has been said with respect to 'links' applies also with respect to 'chains'. Having examined the complete movement of each chain in the way described, it must then be seen that each pair are so linked that when one chain is operated the ensuing movement in the other is possible and of the kind required.

We have not yet considered those cases where the items are so linked that they are not in contact throughout the movement, nor those in which compound links are employed. These, however, differ only in complexity from the simple linkage already examined. As they provide no new difficulty their consideration has been postponed to the Appendix.[1] For similar reasons the analysis of our other tests will also be found in the Appendix, for these too, while clearly showing the presence of the same kind of mental operations as those which we have now examined, failed to disclose any additional processes which could be specially associated with *m*.

THE NATURE OF THE GROUP FACTOR

Having examined the mental processes occurring in those tests which involve *m*, we are now in a position to see more clearly the psychological nature of the latter. It is true that these tests needed the ability to understand the simple instructions given, and a willingness, together with the necessary interest and attention, to carry them out. But such may be said of all mental tests—and they are, moreover, qualities which would tend to diminish the influence and significance of any 'special ability'. By taking groups of subjects of approximately equal mental development and 'training', their influence was reduced to a minimum. The outstanding feature in which the *m*

[1] See p. 199.

tests differ from the customary 'intelligence' tests, and from that part of our own data in which no *m* was found, is the spacial character of the material employed, together with that particular kind of thinking about this material which we have examined. Such thinking involves not merely the apprehending of certain spacially arranged items, as in a design, nor solely in the eduction of their space relations whereby the design is known to have a definite shape, or pattern: superimposed on this definite arrangement of parts is movement—and as the items of the mechanism move their pattern continually changes. The new patterns are not given in the presentation, neither are they formed in haphazard fashion as in a kaleidoscope, but in a certain orderly way. The ground of each new pattern lies in the immediately preceding pattern and must be educed therefrom by means of the space relations between certain of its parts.

The same kind of thinking is clearly present in those other parts of our data in which the group factor occurs, as, for example, in Part II of the Air Ministry's Mental Efficiency Test. In each of the tests comprising this part the subject is presented (in diverse ways) with a certain set of spacial fundaments arranged in a given manner, and is required either to educe the resulting arrangement when they are moved in a certain stated way, or to determine how they must be moved to produce a given arrangement. The same may be said of much of the activity involved in 'Handwork', 'Handicraft' and the 'Trade Test'. This nearly always involves the planning of the shapes into which various parts of an object must be cut in order that when fitted together in a given way they shall make the required object. Similar mental activity is often involved in technical drawing, as when one view of an object, such as its elevation, plan, or section in a certain plane, must be derived from another, as given for example in a sketch or photograph. The specific correlation of the 'School Subjects' (Air Ministry Examination) with the *m* factor

is similarly accounted for. These not only included drawing of the kind just mentioned, but were heavily weighted with problems about various parts of engines, mechanical movements and other spacial material.

Quite different was the case with Part I of the Air Ministry Test, for nowhere in this was it necessary to cognize either spacial fundaments or space relations; neither did these processes enter to any appreciable extent in the ordinary school examination.[1] Here it is important to distinguish between such mere apprehending of shape and form as is required in drawing and modelling from the concrete object in the 'art' lesson, and the eductive work in the *m* tests. These latter require neither the special 'eye' (or 'hand') for nice distinctions in shapes and sizes, nor the executive skill needed in the former, but demand, on the contrary, a considerable degree of eductive thinking. In these respects our tests differ from those of so-called 'practical' ability in which the object is actually constructed, and from those,[2] again, in which a certain inset is selected merely on account of its shape and fitted into its appropriate hole. It is now also evident why our 'Knots' Tests showed little correlation with *m*, for in this test the essential work was to determine whether the twists in a certain part of the string resembled the shape of a knot—it was not necessary to educe the subsequent position of the string, or even possible, for the string would not move as a mechanism. Clearly the presence of *m* depends not only on the spacial character of the material, but also on the kind of thinking to be carried out in relation to that material. Seeing that we avoided, as far as possible, questions which would require special knowledge or training, *m* appears to be best identified with innate aptitude for this kind of thinking.

[1] We have already referred to the difficulty teachers found in trying to estimate their pupils' 'ingenuity' from the work done in the classroom.

[2] Known as 'formboard' tests.

CHAPTER X

SIGNIFICANCE OF THE RESULTS FOR PSYCHOLOGY

THEORIES of Mind. We have seen in Chapter III that the theories regarding the way in which the mind is held to function are of three kinds, namely the 'anarchical', the 'oligarchical' and the 'monarchical'. Our experiments were not especially planned to throw light on this question, and consequently our data are not of the kind it would be necessary to collect in order to put such theories to a crucial test. Nevertheless it may not be altogether unprofitable to ask which of these theories best explains our results. On the anarchical view success at the various activities measured by the tests, estimates and examinations, is dependent on a number of psychical elements or 'factors' which function in entire independence of one another. According to this theory the correlations observed in our data between each pair of tests would be attributed to the occurrence in them of identical elements, i.e. to a number of common factors. We have already noticed the difficulty involved in explaining our super-correlation by a number of independent group factors, rather than by a single group factor. Moreover, our table of 'specific' correlations afforded no indication of a number of common factors, but was, on the contrary, adequately explained by the presence in the mechanical group of a single factor running through it. Our results, then, do not lend support to this theory so far as the per-

formances covered by them are concerned. It would of course be quite a different matter to resolve the group factor itself into a number of more elementary constituents (as, for example, the mental processes involved in the analysis), functioning as a single interdependent group of elements—but as such it would still function as a whole, being merely complex in nature. To this view there would seem to be no objection.

According to the oligarchical view we must attribute success at the various performances to one or more 'faculties' or 'abilities'. Each faculty may involve a number of interdependent activities, but functions apart from the other faculties. Thus there has been postulated a 'mechanical' intelligence acting independently of, and sometimes even assumed to be opposed to the kind of intelligence needed to succeed in school subjects and the intelligence tests. Here, again, our results do not bear out the theory, since they go to show that much in common exists between these two alleged kinds of 'intelligence'.

The monarchical view, in its extreme form, would hold that the successful carrying out of any cognitive operation depends upon the correct functioning of two factors, viz. a factor which that operation shows in common with all other operations—the 'general factor'—and a factor peculiar or 'specific' to that operation itself. Consequently correlation between different mental performances would be due solely to their common general factor, and 'specific' correlation would occur only between simple mental operations of a similar character. We have already seen that our correlations need, for their complete explanation, a factor running through both the 'mechanical' and the 'general intelligence' part of our data, so that with respect to the general factor the monarchical view finds further support here. But we have also evidence that another factor extends its influence over a wide part of our data, viz. the group factor *m*. The activity concerned here is by no means simple in character, but involves many

elementary processes, as the analysis of the M tests has shown, to say nothing of the complex nature of the Passing Out Examination. If the only other factor entering into these various elementary processes were those specific to the kind of process in which they occur their respective influences would tend to cancel one another in the complex performances measured by the tests and technical examinations, and the latter would tend to correlate with each other solely on account of the general factor common to every process. In view of the group factor which we have found, this is evidently not the case, and the extreme form of the monarchical theory needs some modification to meet this point. This seems best done by supposing that ability, at least where 'mechanical' operations are concerned, is dependent on three kinds of factors, viz. a general factor (g) which enters into all cognitive operations, a group factor (m) which restricts its range to a special group of mental operations, and a specific factor or factors (s) peculiar to each particular kind of mental operation. The 'specific' part may be regarded as the unanalysed residue which remains after g and m have been accounted for and in which suitable devised experiments may yet find further group factors of possibly less restricted range than m. Such a view has certain points of correspondence with all three types of theory. In the specific factors we have the independent elements of the 'anarchical' view; but these do not complete the story, for in addition there are the group factor, resembling in its wider though limited range the 'powers' of the 'oligarchical' view, and the general factor,—the all-powerful monarch of the 'monarchical' view.

The Measurement of Mechanical Aptitude. The foregoing discussion bears closely on the problem of measuring a person's ability for the kind of work which we have examined in our tests and which we have found to enter largely into the technical side of mechanical engineering. It has been shown that we may appropriately speak of a

'mechanical' aptitude or a special 'mechanical' ability for this kind of work only in the sense that many of the mental operations which the work calls for depend not only on the general factor *g*, but also on at least one other factor, namely the special factor *m*. Some branches of engineering no doubt require much more *m* than *g*, while in others one might get on quite well with a modicum of *m* provided he had sufficient *g*. But there is no opposition between these factors—both are needed, but in varying degrees.

Our results prove *m* to be of sufficient importance to warrant a careful measurement of it in individuals. The problem of its measurement is, however, complicated by the necessary presence of *g*, and possibly also of 'specific' factors, in any test which may be devised to measure *m*. This difficulty has been met by determining the correlations of the test with *g* and *m* respectively, and then employing these to effect the measurement of *m* itself. Such determinations carried out with respect to the tests employed in the present research give every indication of the successful employment of these tests for this purpose. Having obtained the necessary data, it is now possible to measure an individual's *m* without introducing the gross inaccuracies which result from the usual practice of taking the actual test scores as the measure itself—and this without much additional work.

Relation of 'm' to other 'Abilities'. The relation between what has been called 'mechanical' ability and certain other so-called abilities may now be brought out more clearly. Of these we may mention in particular 'practical ability' and 'motor ability'. A tendency to employ these terms as if they meant much the same thing is at times observable, and this view appears to be reflected in the tests which investigators have employed for measuring them. Thus we have Stenquist's test of 'mechanical ability', in which we found a large element of digital skill, and Dr. MacFarlane's tests of 'practical ability', in which

'mechanical relationships' are said to enter, and which also involve some motor skill.[1] These tests are described by Dr. MacFarlane herself as being both 'constructive and manipulative', and her view as to what they measure may be given in her own words: 'I prefer "practical ability" to "manual ability" because the latter stresses the importance of the act of manipulation whereas our tests show that mere motor dexterity is of comparatively small importance for success in the whole performance. . . . I do not wish to suggest that there is a single general factor common to all practical abilities. I think it much more probable that there is a complex of many factors, that these factors are not always the same, but they tend to be positively correlated.' Other tests, known as 'performance' tests, are said by some to measure 'performance' capacity, by others to measure a kind of intelligence not measured by verbal 'intelligence' tests, while others yet again regard them as tests of *g*.

There would seem to be at least four kinds of practical ability. There is, for example, the work of the designer, involving large *m* but no manual skill; that of the machine operative, involving no *m* but a varying degree of skill according to the machine operated; that of the automatic machine worker and machine minder, which appear to call for neither *m* nor motor skill; and finally, a host of engineering occupations which involve both *m* and some form of motor skill. As a first step towards a clearer insight into these various kinds of practical work it would seem desirable to analyse them with respect to *m*.

To take the case of what has been called 'motor ability': this form of activity was specially avoided in our tests. Seeing, however, that the perception of space is largely developed by the aid of motor sensations, and that the material of the tests was spacial, it might appear at first sight that motor activity was an indirect determinant of

[1] See Dr. MacFarlane, 'A Study of Practical Ability', Monograph Supplement No. 8 to *Brit. Jour. of Psych.*

success in dealing with this material. But the precise estimation of shapes, sizes and distances, in which motor experiences might conceivably play a part, was not required in the tests. The essential processes on which success or failure turned were not perceptual but of the eductive kind in which motor experiences could hardly have assisted.

Another source of confusion between *m* and motor activity may lie in the fact that frequently both *m* and some form of motor skill enter inseparably into the same work. This arises, for example, when the mechanical advantage derived from a tool depends upon the way it is held, as in prizing open a box, or batting a ball. An even closer connection between these two kinds of activity may sometimes be found in what might at first seem to be purely motor activity. This occurs when the 'tool' is some part of the body itself. The skeleton is, after all, a mechanism, and in some activities, such as boxing, success would seem to depend largely upon the ability to use it to the greatest mechanical advantage. A similar intrusion of *m* into motor activity was observable in some of Stenquist's tests where the final act of assembling depended on a certain knack of holding the parts when clipping them together. All these cases are clearly distinguishable from those in which the *m* and the motor skill are easily separable, as when some mechanical object has first to be designed and then made.

FOR EDUCATION

Confirmatory Evidence of 'm'. Turning to education, we may first notice a peculiarity about the educational accomplishments and training of many of our great pioneers in engineering. This consists in the fact that seldom did these excel in school studies but were, more often than not, men of no 'learning' in the ordinary sense of the word. To quote Smiles :—'One of the most remarkable things about Engineering in England is that its principal achievements have been accomplished not by natural philosophers,

nor by mathematicians, but by men of humble station, for the most part self-educated . . . nor did any of the great mechanics, who have since invented tools, engines and machines, at all belong to the educated classes. They received no college education. Some of them could scarcely write their own names. But where learning failed, natural genius triumphed.'[1] And again: 'The greater number of early engineers were the offspring of necessity. Some great work was required to be done, and forthwith a skilled worker (for there were no so-called engineers in those days) was called upon to do it. The work which he had undertaken to accomplish often presented great difficulties and his efforts to overcome them amounted to a succession of individual struggles, sometimes rising almost to the heroic. In one case we find the born Engineer to be a London goldsmith like Myddleton; in another a retired sea-captain, like Perry; a wheelwright, like Brindley; an attorney's clerk, like Smeaton; a mathematical instrument maker, like Watt; a millwright, like Rennie; a working mason, like Telford; a slater, like Clement; or an engine brakesman, like Stephenson.'[2] A similar fact is seen in the history of Engineering in America. Referring to the American industrial revolution of 1820–70, Prof. Mann says: 'A high degree of engineering ability was required to accomplish this industrial revolution. Among the civil engineers who took part were a number who had the advantage of scientific training at Rensselaer or at West Point.[3] But in the long list of mechanical engineers who built the locomotives, the steam engines, the machine tools and the farm machinery, it is difficult to find a single one who had any special school training for the work.'[4] All this suggests that success at engineering is largely

[1] Smiles, *Lives of the Engineers—Early Engineering*, p. xvi.
[2] *Ibid.*, p. xxii. [3] Technical Colleges.
[4] Chas. R. Mann, 'A Study of Engineering Education', *Carnegie Foundation for the Advancement of Teaching*, Bulletin No. 11.

dependent on a special aptitude which hardly enters into the academic studies of the classroom, and which is innate rather than acquired. It conforms with the low correlation of the M tests with the subjects of the elementary school, and provides further highly suggestive evidence of *m*.

Place of 'm' in the School Curriculum. The facts just noticed lead directly to the important question as to the place of *m* in the school curriculum. It seems clear that the ground covered by the schools and colleges was not very fertile where engineering in the early days was concerned. Since then, of course, an attempt to provide a more suitable type of education for the technical worker has been made by the establishment of technical schools and colleges. But children do not ordinarily enter such schools before fourteen, and frequently at a much later age. It is therefore important that a special aptitude such as *m* should find some exercise in the curriculum of the elementary and the secondary school, so that it may have every opportunity of developing, and some reliable knowledge of the pupils' capabilities in this direction may be obtainable. Even in a school where special encouragement was given to practical work it was found impossible to estimate the pupils' 'ingenuity' on the work carried out in the classroom,[1] and the correlations have shown how little *m* enters into these subjects. To find *m* we must turn to such subjects as woodwork and handwork. Even here, however, the correlations will convey a false impression unless it be remembered that our measures of 'ingenuity' were not scores made at the work as such, but estimates of the trait in question so far as its presence in the work was observable by the teacher: the extent to which such work will tax 'ingenuity' must depend largely on the teacher's method. Much of this work is rightly directed to the

[1] Except (in the case of one class only) 'handwork', to which we shall refer immediately.

development of manual skill, as indeed the term 'manual training' implies. Unless therefore the pupils are thrown upon their own initiative, and are encouraged to devise and plan for themselves the objects they make, little opportunity for the exercise of 'ingenuity' is likely to occur here. There is, perhaps, another source whence some exercise of *m* may be derived, namely the practical science lesson, especially where the pupils are required to suggest and fit up their own apparatus.

The manual training centre can usually take only a limited number of pupils from any one school, and handwork frequently plays but a minor part in the curriculum, especially for the brighter pupils, who are encouraged to work for academic scholarships to the secondary schools. There are still many schools in which the laboratory accommodation necessary for the type of science work suggested is lacking. Withal, even when these subjects are amply provided for, the *m* factor, as we have seen, enters only incidentally. In view of this it seems doubtful whether, in an age of mechanical invention, the special aptitude for this kind of work receives in our elementary and secondary schools the encouragement and scope it deserves.

With the technical schools the case is, of course, different, since their curricula are designed to meet special vocational needs. We saw that *m* enters largely into the work of the R.A.F. School, Cranwell. But this school was an advanced institute in which the pupils were not only rigorously selected, but were also expected to reach a very high standard of efficiency. Possibly less 'ingenuity' is called for in the work of junior technical schools, where, on the practical side, it is mainly directed towards developing skill in the use of tools by carrying out standard exercises. But here, again, much will depend upon the teacher's method of handling these subjects.

Influence of 'Selection' on Technical Education. We have already referred to the 'creaming off' of the best

pupils from the elementary to the secondary schools. This is usually effected by means of a scholarship taken at the age of eleven. Unsuccessful candidates and 'late developers' get another chance at thirteen. Trade Scholarships, tenable at trade and junior technical schools, are not ordinarily awarded before the age of thirteen. The aim of both types of scholarship is to select from among the candidates those of highest 'intelligence'. In the case of Trade Scholarships there is, in addition to the 'intelligence' part of the examination (based on Arithmetic and English), a second part consisting of an examination in handicraft and drawing. Only those passing the first part are allowed to sit for the second, but candidates who, having failed in Part I, have previously shown themselves to possess unusual manual dexterity receive special consideration.[1]

Now if, as our results show, *m* functions independently of *g*, we should expect to find it as equally distributed among those who pass into the secondary schools in virtue of their high *g* at eleven, or thirteen, as among those who fail to do so. It follows that only a limited proportion of those pupils who possess a marked degree of *m* will enter for the Trade Scholarships, and some of these may be ruled out through failing in Part I, while the secondary schools will get first pick as regards *g*. It cannot, therefore, be assumed that the technical schools draw the best talent for their particular kind of work ; they are, on the contrary, handicapped in this respect.

It may, perhaps, be argued that the junior technical courses require less *g* than the secondary school course for boys of the same age. This will depend on the standard aimed at in each case, which in turn will depend on the mental calibre of the pupils. But if, as seems essential to the success of our great technical industries, the technical school boy is to carry his general education (including his knowledge of the more theoretical aspects of his technical

[1] We quote the practice of one of our largest education authorities.

work), as far as the secondary pupil, there appears no reason why any differentiation with respect to *g* should be made.[1] Again, it may be thought that the occupations into which the technical products will pass require less *g* than that which awaits the secondary school boys. But here we must compare the work of the former not with the higher professional work which those who stay in the secondary school beyond the age of sixteen to seventeen years may ultimately take up, but with that required in the junior posts which those leaving the secondary school at sixteen to seventeen tend to enter. No doubt a different mentality is required for the two kinds of work, but this difference appears to be one of special aptitude rather than of *g*.

When we come to the higher branches of technical training the influence of 'selection' seems to work in much the same way as before. Thus, to take a typical case, pupils attending the central schools [2] of one of our largest education authorities will not be recommended for an award to a secondary school at the age of thirteen 'unless their ability is such that they are likely ultimately to profit by an advanced course in the secondary school', but these conditions are not laid down for technical scholarships. Pupils turned away from secondary schools on this account may compete for Junior Technical Scholarships, and, later, for Senior Technical Scholarships. And to take the case of a yet higher type of scholarship, the Senior Scholarships in Technology awarded to pupils over eighteen are only given to candidates who have already been in industrial employment, and have attended evening classes. These, then, are hardly likely to go to the 'cream' who, taken

[1] This might, of course, necessitate some reorganization of our technical schools and colleges, and in particular a closer relation between the work of the junior schools, the senior schools and the universities.

[2] Attended largely by pupils who have just failed to secure scholarships at eleven.

into the secondary schools by scholarships at eleven or thirteen, are of sufficient ability to profit by an advanced course of study there. The same tendency is observable in the universities, for here the scholarships awarded in academic subjects far exceed in number those given in applied science and technology. This tendency to differentiate between the two types of pupil according to 'intelligence' appears, from our results, to err by assigning too small a part to *g* in technical work, and almost wholly neglecting *m*.

It is not suggested that the best brains are only to be found within the scholarship group, much less that none of these find their way into engineering and other kinds of technical work. Genius will tend to find its proper channel despite the counter-influences which a well-meaning system might direct upon it. Neither is it maintained that the tendency to direct the best brains into academic rather than technical pursuits is restricted to the method of awarding scholarships and other educational inducements. Custom and tradition will work in the same direction, and are, indeed, largely responsible for the present form which these inducements take. The technical side of education, being of comparatively recent growth, must needs take what it can get. But if the higher branches of engineering are to attract a larger proportion of men well endowed for this kind of work,[1] some better means of discovering the necessary talent, and of directing it into these walks of life, must be found. An important step to this end might be taken by so modifying our scholarship system

[1] The need for this has been voiced, directly or indirectly, in several quarters recently: cf., for example, Sir R. Blair, '. . . yet British industries are languishing and, to give a relevant example, while the first marine engines were planned by Englishmen and while Parsons' turbines are still the foremost of that type of prime mover, continental firms have taken the lead with the Diesel engine, and Americans in the design and manufacture of machine tools.' —*Discussion on Conditions of Success of Technical Education, Brit. Association*, 1925.

that—(1) the most intelligent pupils are not definitely selected at an early age for an 'academic' type of education, but that, on the contrary, equal facilities and inducements to enter technical schools and colleges are held out whenever 'selection' occurs, and (2) more rigorous efforts to discover and measure special aptitudes in the candidates (including, for example, not merely 'manual dexterity', but also 'mechanical aptitude') are made, and differentiation between the two types of education is based largely on these rather than on *g*. At the same time some changes in the organization of our technical schools would be necessary. These would consist largely in: (1) modifying the curriculum of the junior technical schools so as to include a more liberal education for those likely to proceed under the new system to the senior technical schools and universities; and (2) establishing closer co-ordination between the work of the junior and senior technical schools, and between these latter and the universities, so that the best pupils of one grade may be more easily passed on to the next higher grade. These changes would have the further advantage of making passage from the secondary to the technical schools easier at any particular stage.

The Use of 'm' Tests in Conjunction with School Examinations. We have seen that the subjects ordinarily taught at the elementary and secondary schools, which might, under certain circumstances, involve some degree of mechanical ingenuity, also depend on other influences, and in particular, on manual skill. Where, therefore, it is proposed to make some difference in the curriculum according to the special abilities of the pupils, or to guide them in their choice of studies or vocation, it would seem desirable to include as part of the school examination some such exercise as the M tests, in which the pupils' ingenuity is more clearly measured. This applies especially to examinations for trade and technical scholarships where, seeing that the child's future studies and vocation will turn largely on the result, the discovery and measurement of

special aptitudes is particularly important. The M tests provide a more reliable measure of this special ability than was obtainable by teachers' estimates, were less subject to the influence of 'age', and possess the further advantage of being objective.[1] As such they lend themselves to standardization.

A group of these tests should also prove a useful adjunct to the examinations of the technical school, especially where it is required to differentiate the pupils with respect to the particular trade, or branch of engineering, they are to take up. Some notion of the extent to which ability at the tests is significant of ability at such examinations may be gained from their correlations with the 'passing out' examination of the R.A.F. School, Cranwell (Table XIX). A candidate's 'passing out' grade is determined by the sum of the marks scored on both parts of this examination, namely the theoretical and practical examination in trade knowledge (T), and the examination in the (mainly) technical subjects (S) of the school curriculum. Reference to the details of the examination given in Chapter V will show that the combined score provides a particularly comprehensive and searching measure of the student's ability to profit by this type of training.

We may first inquire how far an examination composed entirely of the psychological tests taken by these candidates, viz. E_3, M, A_2, I, A_1, is likely to serve as an index of success at the technical school course as measured by the abovementioned combined score at the Passing Out Examination. The answer is given by the correlation of the sum of these tests (in which equal weight was given to each) with T + S, which proves to be no less than ·76. Seldom do school examinations correlate higher with themselves.[2] This figure also compares well with the correlations ordin-

[1] See p. 106.

[2] See, for example, the numerous correlations of this kind given by B. D. Wood in *Measurement in Higher Education*, World Book Co., 1923.

arily obtained between 'intelligence' tests and school examinations of the academic type. Thus, at Columbia College, where this question has been thoroughly studied, nowhere did the correlation between the 'intelligence' tests and the carefully worked out measures of 'College Success' there employed exceed ·672.[1] We should not, of course, expect perfect correlation between the psychological tests and the school examinations, even if each of these provided a perfect measure of its kind, for qualities of character, interests, and other influences which hardly enter into the tests will go far towards deciding the school examination results. Indeed, it is in order to measure innate ability in relative isolation from these other factors that resort to the psychological tests becomes necessary. The high correlation noticed above, together with the fact that the group of tests occupied three hours while the Passing Out Examination took thirty, augurs well for their employment in this connection.

Again, we may inquire how far each of the two kinds of tests, considered separately, agree with the Passing Out Examination. This is given by the correlation of $(T + S)$ with the mechanical group $(E_3 + M + A_2)$ and with the 'intelligence' group $(I + A_1)$, respectively. The figure in the former case is $\cdot 64 \pm \cdot 03$, and in the latter $\cdot 42 \pm \cdot 04$. The 'mechanical' group occupied one hour forty minutes, the 'intelligence' group one hour twenty minutes. The difference between the two coefficients is not due to the slightly longer time devoted to the 'mechanical' tests, since $(E_3 + M)$ alone, occupying only one hour, correlates $\cdot 60 \pm \cdot 03$ with $(T + S)$. It is obviously explained by the presence of *m* in both $(T + S)$ and the 'mechanical' tests and its absence from the 'intelligence' tests. These figures again bring out the importance of considering *m* when selecting candidates for technical courses.

The total score at the Passing Out Examination is but a blurred impression of the various factors upon which the

[1] As reported by B. D. Wood in *Measurement in Higher Education*.

successful pursuit of the three years' previous training must have depended. It is one of the aims of psychological tests to isolate as far as possible the more important of these and, by measuring them in relative independence, to present them in a clearer view—especially so with respect to innate abilities. In the present instance a step towards this was made in the examination itself, by having separate scores for the part which related more definitely to the practical side of the course, T, and that which aimed at testing a knowledge of the school subjects, S. Nevertheless, we have seen that T involves both g and m, to say nothing of other qualities upon which success at a lengthy technical course must turn. On the other hand, the psychological tests provide a means of measuring m in isolation from other factors, and this to a high and known degree of accuracy.

FOR INDUSTRY

Four Kinds of Problem. The considerations to which we now turn are, of course, intimately related to those of our last section, for it is evident that any particular kind of technical education must take into account the problems of the industry which it serves. The problem of discovering the mental factors involved in 'school work' is obviously akin to that of determining those involved in various forms of work—the problem of vocational and occupational analysis. Similarly the problem of selecting pupils for special kinds of education is much the same, psychologically, as that of selecting applicants for special kinds of work, although it is convenient to distinguish the two by the terms 'educational selection' and 'vocational selection', respectively. The latter, on the contrary, presents a different problem from that of 'vocational guidance', for whereas in making a selection we have merely to estimate the applicants' fitness for a specific kind of work, in giving 'guidance' we must consider the individual's chances of success in many different walks of life. The character of

the work with which the psychologist is concerned is also apt to differ in the two cases, being usually well defined 'occupations' or 'jobs' where selection is required, but the more complex 'vocations' where guidance is sought. A somewhat different problem is again presented by what may be called 'vocational placement'. This arises when a large firm, having already selected its employees, wishes to place them to the best advantage in its various departments. Such differentiation between its personnel will frequently occur where it is found necessary to choose the workers according to the general requirements of the work [1] and then to give them a certain amount of training in the special work of the department to which they are allocated. In so far as some scope for choice is possible, such a problem resembles that of vocational guidance, but in the restricted and clearly defined nature of that choice, it is closely allied to that of selection. While these four kinds of problem differ from one another in certain important respects all alike demand the recognition and measurement of the differences in mental make-up to be found among individuals. One such difference, of an important and far-reaching character where engineering is concerned, appears to be the *m* disclosed in our results.

Occupational Analysis. The analysis of the activities involved in various kinds of work is a necessary step towards solving the other problems mentioned above. On this work of analysis our results have an obvious and direct bearing, for by measuring the *m* of persons actually engaged in the work to be analysed, and determining the correlation of this with known ability at the work, we should be able to see how far success at the latter depends on *m*. Since, for this purpose, a reliable measure of the work is required, we can hardly hope to go, at present, beyond the more restricted kinds of work more aptly called 'occupations' and 'jobs'. Yet in so far as these

[1] And also, perhaps, according to the condition of the labour market.

occupations enter into the wider ' vocations ', such analysis would constitute a step towards analysing the latter. Further light on the mental requirements of the vocations may be expected from a similar analysis carried out with respect to the activities involved in the training for these, as for example, in learning the various subjects required for an engineering degree.

Occupational Selection. The *m* tests would seem to find another direct use in the problem of selecting suitable applicants for those engineering occupations which are found to involve *m*. Such occupations may be expected to occur in every large engineering firm where mass production renders a fine division of labour possible and necessary. The mental requirements may vary considerably from one occupation to another within the same firm. Hitherto, attention has been chiefly focused on the motor and sensory aspects of this kind of work. While various forms of sensory activity and motor skill must obviously enter into the bulk of these occupations, a careful analysis may be expected to show that many also involve *m*. We have already noticed that even where the occupations may seem at first to be purely manual they may differ with respect to ' ingenuity '. Thus, the work of assembling or of toolmaking appears to require more *m* than that of gauging or machine-operating, and that of assembling a fairly complicated object like a typewriter more than that required to assemble a bicycle pump. It is possible, too, that in some kinds of work, such as assembling, the *m* factor plays a larger part during training than subsequently. Where this is the case and, as often happens, the applicants have had no previous experience of the work, it seems particularly desirable to include some test of *m* in the psychological examination.

Distinguishable from the above-mentioned ' occupations ' are the engineering ' trades ', for these cover a wider range of activities and demand more technical knowledge than the former. Consequently they usually require a lengthy

period of apprenticeship training. It was into work of this character that our R.A.F. students passed. As skilled 'mechanics' they were expected to know the technical processes of their craft. For this type of worker selection will (or should) have already operated before and during the training period. The selection of such workers must depend largely upon their previous record and experience. At the same time, where a choice of applicants is possible and the trade demands *m*, the employment of psychological tests of this factor should prove an additional aid in selecting those most fitted for the work.

Occupational Placement. We have suggested the term 'occupational placement' to indicate the distribution (or redistribution) of workers among the various departments of a firm in such a way that, so far as is possible, each member gets the work for which he is most fitted by nature and training. In this, the efficiency of the staff as a whole is the primary consideration. Consequently, not only the ability of the workers, but also the demands of the several departments must be taken into account.[1] This renders the problem more complicated than that of selection. The work of a large engineering firm may, by including many occupations and trades, afford scope for a wide range of mental qualities in its employees. To place the latter to the best advantage will usually necessitate a more extensive psychological examination of each individual than would be required in selecting applicants for any single type of work. In view of our results, such an examination would seem to be very incomplete unless it took some account of *m*, and of the differences between the various trades—and sometimes even branches of the same trade[2]—with respect to their dependence on this factor.

[1] With regard, for example, to the number of workers required in each.

[2] Compare, for example, the work of the wireless operator with that of the wireless mechanic; that of the electrician with the work of the electrical fitter; and the various other branches of the fitter's trade with one another.

Even in the placement of the professional engineer there appears no reason why tests of mechanical aptitude should not serve a useful purpose. A good example of such a problem is that studied by Dr. B. V. Moore, to which we referred in Chapter II. The main question here was to differentiate, in the case of a group of engineers who had received the same general engineering training, those most suited to become 'design engineers' from those best employed as 'sales engineers'. Such a division would seem to turn largely on the amount of *m* possessed by these men.

Vocational Guidance. The factors upon which the choice of vocation rests are generally more numerous and complex than those presented for consideration in 'selection' or 'placement'. The scientific evaluation of these factors is therefore usually more difficult in the case of vocational guidance. At the same time its consequences for the individual and the nation are more far-reaching. In most cases, vocational guidance will require a wider survey of the individual's natural endowments than is necessary in 'selection' or 'placement', for whereas in either of the latter it is sufficient to measure the particular qualities required for a known kind of work, the former demands a view of the person's whole 'make-up'. As an important constituent of this, and one of great vocational significance, the *m* factor would seem, from our results, to call for recognition and measurement in any general mental survey of this kind.

With our present limited knowledge of vocational requirements such measurements have probably their most immediate application in providing a negative kind of guidance as to the sort of employment a person is decidedly unsuited for. The measurement of *m* should be directly serviceable in this way by enabling a large number of engineering occupations to be definitely ruled out for those who are clearly lacking in this aptitude. Where, on the contrary, a high degree of mechanical aptitude exists,

positive guidance into some branch of engineering which this would suggest must be given with caution since there are other factors besides m to be considered—and notably among them, g. The question of technical knowledge and training must also be taken into account. The importance of coupling these with 'innate ingenuity' is clearly seen in the many attempts to invent perpetual motion where a little knowledge of the laws of mechanics would have saved a deal of mis-spent ingenuity. Such attempts have usually indicated a high level of mechanical aptitude. To these must be added those cases where, through the absence of a favourable environment, the latent aptitude in the child has remained for ever unexpressed. Is it too much to hope that vocational tests of m may in future discover at least some of this talent in time to direct it into suitable channels for training, so that it may bear fruit more profitable to the nation and to the individual himself?

CHAPTER XI

GENERAL SUMMARY

1. NEED *for Research.* Although frequent assumptions concerning a 'mechanical' ability and its relation to other 'abilities' have been made, scientific evidence on these points, based on valid objective criteria, has been entirely lacking. The matter was deemed of sufficient importance for psychological theory and practice to warrant an investigation into the whole question as to the existence, nature and measurement of this so-called 'ability'.

2. *Construction of New Tests.* It was found necessary to devise and 'try out' new tests. Those ultimately retained fall into four broad groups, viz.: (*a*) mechanical models, (*b*) mechanical completion, (*c*) mechanical explanation, and (*d*) mechanical diagrams. Their reliability proved to be generally high; marked correlation was found between the various sub-tests constituting each test. In this, and other ways, they proved suitable as group tests. (Tables I–X.)

3. *The Data.* The new tests were given: (1) to 88 Commerce Students, (2) to 114 Elementary School Boys, and (3) to 228 R.A.F. Mechanics. Estimates of 'ingenuity' and position in class at school examinations were obtained for the elementary school boys. The R.A.F. subjects also took Prof. Spearman's 'intelligence' test, the Air Ministry's Mental Efficiency test, and the Air Ministry's Passing Out Examination.

4. *The General Factor—'g'.* A certain amount of correlation was observed between all the various parts of our data. The results thus far support the theory of *g*.

5. *Existence of m.* Our results further demonstrate the existence of another factor—a group factor running through those operations in which the subject is called upon to deal mentally with mechanical movements. This is best conceived (subject to further research) as a unitary factor, rather than as a number of independent factors. It is a mental factor, operating always in conjunction with *g*, rather than a concrete 'ability'—hence we have preferred to call it *m*.

6. *Measurement of 'm'.* The method of measuring *m* has been indicated. The correlation of our tests, and certain other parts of our data, with *m* have been determined. These provide an important check on the accuracy of our measures. It has been shown that a fairly high degree of accuracy should be attained by nine of the tests.

7. *Nature of 'm'.* Subjective analysis has shown that the processes involved in *m* are essentially of the eductive kind in which the correlates and relations are largely spacial in character. This, together with an examination of the test material, suggests that *m* is more akin to an innate aptitude than to an acquired ability.

8. *Bearing of Results.*

(*a*) *On Psychological Theory.* The results have a significant bearing on psychological theory. What has been called 'mechanical ability' or 'mechanical intelligence' is not opposed to 'general intelligence', both have *g* in common. Only in the sense that it involves a 'special' or 'group' factor (as opposed to the general factor) may we appropriately speak of a special 'mechanical ability'. The concrete ability is resolvable, in the light of our results, into: (1) the general factor, *g*; (2) the group factor, *m*; and (3) one or more factors 'specific' to the particular 'mechanical' task in question. Similarly 'practical' ability, and possibly also 'motor' ability, and certainly

'performance' ability, call for closer analysis with respect to *m* and *g*.

(*b*) *On Educational Practice.* The results also point to important corollaries relating to educational practice, and, in particular, to the importance of (1) making definite provision for the exercise of the mental processes underlying *m*, and (2) measuring, and taking into account, the pupil's *m* when differentiation in the school curriculum is contemplated.

(*c*) *On Mental Testing in Industry.* The results, finally, indicate the importance of *m* in industry, and suggest that the tests should find a valuable practical application in the work of (1) occupational analysis, (2) occupational selection, (3) occupational placement, and (4) vocational guidance.

APPENDIX

I. TABLES

Table I

Series I (Commerce Students). Inter-correlation of 'Models' tests.

Subjects.	No. taken.	Inter-correlation.
Group I. 40 Ex-service men. .	4	·80 ± ·02 (av.)
Group II. 10 boys, 16 girls, average age 15 years 8 months . .	4	·87 ± ·01 (av.)
Group III. 12 boys, 10 girls, average age 14 years 6 months	2	·63 ± ·08
Group A. 22 boys of Groups II and III above	2	·77 ± ·06
Group B. 26 girls of Groups II and III above	2	·70 ± ·07

Table II

Series II (Elementary School Boys). Average inter-correlation of the three 'Models' tests.

Subjects.	Average Inter-correlation.
Group IV. 36 elementary school boys, average age 12 years 11 months	·75 ± ·03
Group V. 37 ditto, average age 12 years 5 months	·47 ± ·05
Group VI. 41 ditto, average age 11 years 5 months	·52 ± ·05

TABLE III

Series II (Elementary School Boys). Correlation between the halves of the 'Models' tests.

Subjects.	M_5.	M_6.	M_7.	Average.
Group IV . . .	·74 ± ·06	·73 ± ·06	·80 ± ·05	·76 ± ·03
Group V . . .	·65 ± ·08	·77 ± ·05	·68 ± ·07	·70 ± ·04
Group VI . . .	·64 ± ·07	·65 ± ·07	·77 ± ·05	·69 ± ·04
All subjects (114) .	·68 ± ·04	·72 ± ·03	·75 ± ·03	·71 ± ·02

TABLE IV

Series II (114 Elementary School Boys). Test M_5 ('Models'). Inter-correlation of sub-tests. (Dec. points omitted.)

	a	b	c	d	e	f	g
a		27	41	46	50	40	44
b	27		45	31	28	38	35
c	41	45		52	39	40	43
d	46	31	52		41	43	37
e	50	28	39	41		29	25
f	40	38	40	43	29		29
g	44	35	43	37	25	29	
Av.	41	34	43	42	35	37	36

Average of 63 coefficients = ·38.
All coefficients over ·29 exceed $4\frac{1}{2}$ p.e.

TABLE V

Series II (114 Elementary School Boys). Test M_6 ('Models'). Inter-correlations of sub-tests. (Dec. points omitted.)

	a	b	c	d	e	f	g	h
a		38	27	28	34	30	27	28
b	38		40	30	31	44	44	48
c	27	40		59	55	46	50	28
d	28	30	59		42	41	44	34
e	34	31	55	42		58	37	28
f	30	44	46	41	58		48	52
g	27	44	50	44	37	48		45
h	28	48	28	34	28	52	45	
Av.	30	39	44	40	41	46	42	38

Average of 84 coefficients = ·40.
All coefficients over ·29 exceed $4\frac{1}{2}$ p.e.

TABLE VI

Series II (114 Elementary School Boys). Test M_7 (' Models '). Inter-correlation of sub-tests. (Dec. points omitted.)

	a	b	c	d	e	f	g	h
a		41	36	56	25	33	44	28
b	41		49	54	22	32	44	24
c	36	49		46	25	46	45	32
d	56	54	46		15	43	46	23
e	25	22	25	15		19	05	39
f	33	32	46	43	19		47	35
g	44	44	45	46	05	47		35
h	28	24	32	23	30	35	35	
Av.	38	38	40	40	20	36	38	30

Average of 84 coefficients = ·35.
All coefficients over ·29 exceed $4\frac{1}{2}$ p.e.

TABLE VII

Series II (114 Elementary School Boys). Test E_3 (' Mechanical Explanation '). Inter-correlation of sub-tests. (Dec. points omitted.)

	a	b	c	d	e
a		32	42	27	44
b	32		49	50	33
c	42	49		50	37
d	27	50	50		26
e	44	33	37	26	
Av.	36	41	45	38	35

Average of 30 coefficients = ·39.
All coefficients over ·29 exceed $4\frac{1}{2}$ p.e.

TABLE VIII

Series II (114 Elementary School Boys). Test C ('Mechanical Completion'). Inter-correlation of sub-tests. (Dec. points omitted.)

	a	b	c	d	e	f
a		40	44	52	31	39
b	40		36	63	28	52
c	44	36		52	49	49
d	52	63	52		40	51
e	31	28	49	40		66
f	39	52	49	51	66	
Av.	41	44	46	52	43	51

Average of 45 coefficients = ·46.
All coefficients over ·29 exceed $4\frac{1}{2}$ p.e.

TABLE IX

Series I (Commerce Students). Test D ('Mechanical Diagrams'). Group II, Inter-correlation of the sub-tests. (Dec. points omitted.)

	a	b	c	d	e	f
a		74	72	45	80	60
b	74		65	34	60	47
c	72	65		41	80	51
d	45	34	41		65	75
e	80	60	80	65		56
f	60	47	51	75	56	
Av.	66	56	62	52	68	58

Average = ·66. All coefficients over ·49 exceed $4\frac{1}{2}$ p.e.

TABLE X

Reliability of tests compared. Correlation between 'halves'.

Series I (Commerce Students).	'Models.'	'Explanation.'	'Completion.'	'Diagrams.'
Group I	·80 ± ·02	·55 ± ·06	—	·71 ± ·05
Group II	·87 ± ·01	·52 ± ·07	—	·76 ± ·06
Group III	·63 ± ·08	·63 ± ·10	—	—
Average	·77 ± ·02	·56 ± ·04	—	·74 ± ·04
Series II (Elementary School Boys).				
Group IV	·76 ± ·03	·48 ± ·10	·64 ± ·08	·45 ± ·10
Group V	·70 ± ·04	·59 ± ·08	·81 ± ·05	·54 ± ·09
Group VI	·69 ± ·04	·54 ± ·09	·59 ± ·08	·44 ± ·10
Average	·71 ± ·02	·54 ± ·05	·68 ± ·04	·48 ± ·06

TABLE XI

Inter-correlation between the tests. Group I (Commerce Students). (Dec. points omitted.)

		M_1	M_2	M_3	M_4	E_1	E_2	EC	D	K
'Models'	M_1		90	89	82	57	75	79	89	21
	M_2	90		69	67	64	77	66	54	37
	M_3	89	69		83	51	58	62	87	26
	M_4	82	67	83	**M**	52	62	61	59	33
'Explanation'	E_1	57	64	51	52		78	45	70	16
	E_2	75	77	58	62	78		61	64	23
'Explanation' and 'Completion'	EC	79	66	62	61	45	61		54	28
'Diagrams'	D	89	54	87	59	70	64	54		50
'Knots'	K	21	37	26	33	16	23	28	50	
Average excluding K		80	70	71	67	69	68	61	68	

All coefficients over ·41 exceed $4\frac{1}{2}$ p.e.

Average of square 'M' = ·69.

" " K v. rest = ·29.

TABLE XII

Inter-correlation between the tests. Group II (Commerce Students, 10 boys and 16 girls, average age 15 years 8 months). (Dec. points omitted.)

	M_1	M_2	M_3	M_4	E_1	E_2	EC	D	K	G
M_1		79	96	84	69	73	81	72	06	27
M_2	79		84	88	82	75	83	65	—10	23
M_3	96	84		90	78	74	82	67	—09	26
M_4	84	88	90		79	69	77	71	—12	26
E_1	69	82	78	79	M	70	78	54	09	13
E_2	73	75	74	69	70		73	45	06	26
EC	81	83	82	77	78	73		60	—09	08
D	72	65	67	71	54	45	60		08	19
K	06	—10	—09	—12	09	06	—09	08		37
G	27	23	—26	26	13	26	08	19	37	
Av. M–D	79	79	82	80	73	68	76	62	—01	21

All coefficients over ·43 exceed $4\frac{1}{2}$ p.e.

Average of M = ·76.

Average of A = ·10.

TABLE XIII

Inter-correlation between the tests. Group III (Commerce Students, 12 boys and 10 girls, average age 14 years 6 months). (Dec. points omitted.)

	M_1	M_3	E_2	EC	K
M_1		63	69	78	48
M_3	63		55	57	34
E_2	69	55	M	86	51
EC	78	57	86		43
K	48	34	51	43	

Average of M = ·68.

Average of K v. rest = ·44.

All coefficients over ·5 exceed $4\frac{1}{2}$ p.e.

TABLE XIV

Inter-correlation between the tests. Group A, 22 boys of Groups II and III 'pooled'. (Dec. points omitted.)

	M_1	M_3	E_2	EC	K
M_1		77	72	84	37
M_3	77		59	66	38
E_2	72	59	M	77	17
EC	84	66	77		28
K	37	38	17	28	

Average of M $= \cdot 73$.
Average of K v. rest $= \cdot 30$.

TABLE XV

Inter-correlation between the tests. Group B, 26 girls of Groups II and III 'pooled'. (Dec. points omitted.)

	M_1	M_3	E_2	EC	K
M_1		70	60	75	−06
M_3	70		51	64	28
E_2	60	51	M	54	23
EC	75	64	54		−07
K	−06	28	23	−07	

Average of M $= \cdot 62$.
Average of K v. rest $= \cdot 10$.

TABLE XVI

Inter-correlation of M tests and School Examinations.—114 Elementary School Boys. (Dec. points omitted.)

		M_5	M_6	M_7	E_3	C	D	X_1	X_2	X_3	Age
M Tests.	M_5		53	63	31	49	44	15	19	16	02
	M_6	53		58	27	51	37	12	08	12	−02
	M_7	63	58	M	36	56	55	20	18	25	−02
	E_3	31	27	36		50	45	25	17	33	−07
	C	49	51	56	50		43	19	13	22	−07
	D	44	37	55	45	43		17	27	14	−03
School Examinations.	X_1	15	12	20	25	19	17		40	60	−16
	X_2	19	08	18	17	13	27	40	E	42	07
	X_3	16	12	25	33	22	14	60	42		−12
	Age	02	−02	−02	−07	−07	−03	−16	07	−12	

All coefficients over $\cdot 26$ exceed $4\frac{1}{2}$ p.e.

Average of M group $= \cdot 47$.

" " E " $= \cdot 47$.

" " M v. E $= \cdot 19$.

Table XVII

Inter-correlations of M tests, estimates of 'ingenuity' based (1) on woodwork and (2) on technical drawing, and school examinations. Influence of 'age' eliminated from 'woodwork' and 'drawing'. (r 'age' v. woodwork = ·14, r 'age' v. drawing = ·18.) 59 Elementary School Boys. (Dec. points omitted.)

		M_5	M_6	M_7	E_2	C	D	W	Dr	X_1	X_2	X_3
M Tests	M_5		57	73	26	46	29	27	28	06	01	01
	M_6	57		66	31	55	48	47	51	11	02	17
	M_7	73	66	M	46	56	78	40	36	11	−06	17
	E_2	26	31	46		62	54	41	54	12	−03	32
	C	46	55	56	62		51	39	48	24	07	26
	D	29	48	78	54	51		45	49	12	12	11
Woodwork	W	27	47	40	41	39	45		84	06	12	17
Drawing	Dr	28	51	36	54	48	49	84		22	−18	29
School Examinations	X_1	06	11	11	12	24	12	06	22		48	56
	X_2	01	−02	−06	−03	07	12	12	−18	48		26
	X_3	01	17	17	32	26	11	17	29	56	26	

All coefficients over ·35 exceed $4\frac{1}{2}$ p.e.

Averages:

M group = ·52. E group = ·43.
M " v. E group = ·11 rectangle C.
M " v. woodwork and drawing = ·42 " A.
E " v. " " " = ·11 " B.

Table XVIII

Inter-correlations of M tests, Teachers' estimates of 'ingenuity' based on (1) home handicraft (H) and (2) school handicraft (S), and school examinations (X). Influence of 'age' eliminated from H and S. 36 Elementary School Boys (Group IV, average age 12 years 11 months). (Dec. points omitted.)

		M_5	M_6	M_7	E_3	C	D	H	S	X_1	X_2	X_3	Age
M Tests	M_5		73	83	47	69	38	25	33	26	11	25	−06
	M_6	73		70	27	62	44	18	08	07	06	20	−06
	M_7	83	70		43	68	60	35	30	16	08	25	−07
	E_3	47	27	43	M	46	43	47 A	48	40	29	28	09
	C	69	62	68	46		55	48	26	28	00	29	−05
	D	38	44	60	43	55		49	19	31	43	11	−05
	H	25	18	35 A	47	48	49		27	−01	14 B	−09	40
	S	33	08	30	48	26	19	27		20	19	−01	50
School Examinations	X_1	26	07	16	40	28	31	−01	20		06	79	−15
	X_2	11	06	08	29	00	43	14 B	19	06	E	26	25
	X_3	25	20	25	28	29	11	−09	−01	79	26		−07

All coefficients over ·43 exceed $4\frac{1}{2}$ p.e.

Averages. Square M = ·55 (M tests).
Rectangle E = ·37 (School Examinations).
" A = ·32 (M tests v. H and S).
" B = ·07 (Exams. v. H and S).

Table XIX

Inter-correlations of M tests, Air Ministry's Tests, 'Intelligence' Tests and Passing Out Examination (R.A.F. School), Parts I and II. (Dec. points omitted.) 228 Trained Mechanics.

		E_3	M	A_2	T	I	A_1	S
M Tests	E_3		48	47	38	38	19	52
	M	48		44	40	17 B	29	51
Pt. I, Air Ministry Test	A_2	47	44	A	43	37	35	50
Trade Knowledge	T	38	40	43		28	15	57
'Intelligence' Tests	I	38	17 B	37	28		41	54
	A_1	19	29	35	15	41		30
Technical Subjects	S	52	51	50	57	54	30	

All coefficients over ·20 exceed $4\frac{1}{2}$ p.e.

Average of A = ·43.

" " B = ·27.

Table XX

Coefficients of 'intellective saturation', i.e. correlations with *g*. Data from 114 Elementary School Boys.

M Tests.

$r_{M_5 g} = \cdot 24$ $\quad r_{E_2 g} = \cdot 36$

$r_{M_6 g} = \cdot 15$ $\quad r_{Cg} = \cdot 26$

$r_{M_7 g} = \cdot 30$ $\quad r_{Dg} = \cdot 22$

Examinations.

$r_{X_1 g} = \cdot 70$

$r_{X_2 g} = \cdot 59$

$r_{X_3 g} = \cdot 77$

Average $r_{\textit{Mechanical v. g}} = \cdot 26$

" $r_{\textit{Examinations v. g}} = \cdot 69$

Table XXI

Coefficients of 'intellective saturation', i.e. correlation with *g*. Data from 228 R.A.F. Mechanics.

'Mechanical' Group.

$r_{E_3 g} = \cdot 41$ $\quad r_{A_2 g} = \cdot 57$

$r_{Mg} = \cdot 36$ $\quad r_{Tg} = \cdot 32$

'Intelligence.'

$r_{Ig} = \cdot 73$

$r_{A_1 g} = \cdot 61$

$(r_{Sg} = \cdot 63)$

Average $r_{\textit{Mechanical v. g}} = \cdot 41$

" $r_{\textit{Intelligence v. g}} = \cdot 67$

Table XXII

'Specific' Correlation, i.e. correlation remaining after influence of g is eliminated from Table XVI. 114 Elementary School Boys. (Dec. points omitted.)

		M_5	M_6	M_7	E_3	C	D	X_1	X_2	X_3
M Tests	M_5		51	60	25	46	41	−03	06	−04
	M_6	51		57	23	49	35	02	00	00
	M_7	60	57		28	52	52	−02	00	03
	E_3	25	23	28		45	41	00	−06	09
	C	46	49	52	45		40	01	−03	03
	D	41	35	52	41	40		02	17	−05
School Examinations	X_1	−03	02	−02	00	01	02		−02	13
	X_2	06	00	00	−06	−03	17	−02		−07
	X_3	−04	00	03	09	03	−05	13	−07	

All coefficients over ·26 exceed $4\frac{1}{2}$ p.e.

Table XXIII

'Specific' Correlation—the 'Models' tests (M) of Table XXII averaged. (Dec. points omitted.)

		M (av.)	E_3	C	D	X_1	X_2	X_3
M Tests	M (av.)	[56]	25	49	43	−01	02	00
	E_3	25		45	41	00	−06	09
	C	49	45		40	01	−03	03
	D	43	41	40		02	17	−05
School Examinations	X_1	−01	00	01	02		−02	13
	X_2	02	−06	−03	17	−02		−07
	X_3	00	09	03	−05	13	−07	

Table XXIV

'Specific' Correlation, i.e. influence of g elimited from Table XIX. 228 R.A.F. Mechanics. (Dec. points omitted.)

		E_3	M	A_2	T	I	A_1	S
'Mechanical'	E_3		39	31	29	13	−08	34
	M	39		31	32	−14 B	14	39
	A_2	31	31	A	32	−08	00	22
	T	29	32	32		07	06	40
'Intelligence'	I	13	−14 B	−08	07		−06	12
	A_1	−08	14	00	06	−06		−10
Subjects	S	34	39	22	40	12	−10	

All coefficients over ·20 exceed $4\frac{1}{2}$ p.e.

Table XXV

Correlation with m. The M tests taken by 114 Elementary School Boys.

$r_{M_5 m} = \cdot 68$ $r_{E_3 m} = \cdot 46$

$r_{M_6 m} = \cdot 65$ $r_{Cm} = \cdot 72$

$r_{M_7 m} = \cdot 79$ $r_{Dm} = \cdot 63$

Average $= \cdot 66$.

Table XXVI

Correlations with m. Data from 228 R.A.F. Mechanics.

M Tests $\begin{cases} r_{E_3 m} = \cdot 58 \\ r_{Mm} = \cdot 64 \end{cases}$ Trade Knowledge $r_{Tm} = \cdot 58$ (Passing Out Exam.) Subjects $r_{Sm} = \cdot 59$ (Passing Out Exam.)

Pt. I. Air Ministry's Test $r_{A_2 m} = \cdot 49$

Average $= \cdot 58$.

II. FURTHER ILLUSTRATIONS OF PROCESSES INVOLVED IN THE *m* TESTS

A. Cases from 'Models' Tests

(1) *Cases where the method is badly applied.*

The importance of the eductive processes in what we have called 'applying the method' is further brought out by those cases where the 'method', although in general correct, is

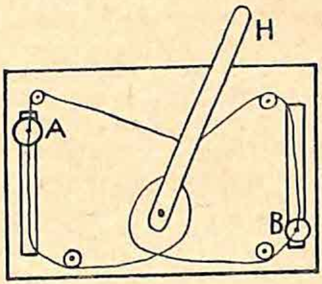


Fig. 13.

badly applied. The following cases illustrate this:—Buttons A and B (Fig. 13) are worked up and down their slots by a to-and-fro movement of H. The pulleys and strings constitute the subject's 'method'. It is evident that while the underlying idea is sound the detailed application is faulty largely through failure to educe the correct space relations between the various strings and handle.

A and B (Fig. 14) are buttons which move along parallel slots. Where one button is pushed along the other moves in an opposite direction. Here, again, the method, that of pulleys and strings, is satisfactory, but owing to weakness in cognizing the necessary space relations between the move-

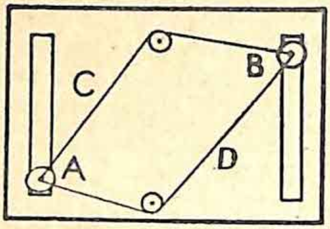


FIG. 14.

ments of the strings and those of the buttons (and hence the shape of the strings) it is faultily applied.

(2) *Cases where the 'linked' items are not initially in contact.*

We consider here the processes involved in 'testing the method' in the case where the items are so linked that they are not in contact when in their initial positions. Fig. 15 illustrates a case in point, where R is the 'operating' rod, S the 'operated' rod. It is required to cognize how S will move when R is pushed in the direction of the arrow, the two

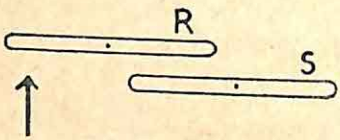


FIG. 15.

rods working in the same plane. This case differs from that already considered only with respect to step (2), for here the space relation between the two items at the time of the initial thrust of one upon the other is not given in the presentation. It can, however, be readily educed when the position of the operating item R at this moment is known. This position is itself educed, as a correlate, being known to be that position which R occupies at the moment it comes into contact with the 'operated' item S. Having cognized this position, the rest of the task can proceed as before.

(3) *Case of 'Compound' Linkage.*

The case of 'compound' linkage differs from that of simple linkage only in being more complex. Fig. 16 will illustrate.

Here the simple link A is linked to, and operates, the complex link B–C. It is required to determine how A, B and C will move when the end *r* of A is moved in an anti-clockwise direction. As before, steps (1) and (2) are carried out with respect

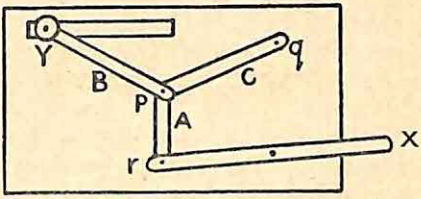


FIG. 16.

to the 'operating' item, what must ensue in C is determined by pivot *q*, and known by reproduction. The kind of movement in B, determined by Y, is similarly known. Whence it is seen that when *r* moves, *p* maintains a constant distance from *q* and Y. From this known constant relation ('distance') of *p* to *r* and *q*, the correlative positions through which *p* must pass, as *r* moves (*q* being fixed) are educible; and from this known space relation of Y to *p*, the correlative position of Y, as *p* moves, may be found. Hence the correlative positions through which A, B and C must pass as *r* moves are known. The whole movement will be cognized as 'possible' so long as the resulting position into which *r* moves is such that a correlative position of *p* at the necessary distance from *r*, *q* and *x* may be found.

B. Analysis of 'Mechanical Explanation' Tests

The solving of the 'mechanical explanation' test falls into two stages, viz. (1) making clear the nature of the various parts of the depicted mechanism and (2) determining how certain parts move when other parts are 'operated' in a given way.

First Stage. To make clear the meaning of the diagram the subject must (*a*) read the description, (*b*) refer the names of the items mentioned to the correct letters in the diagram, and (*c*) regard the parts of the diagram so lettered as the concrete object whose name it bears.

The descriptions were given in simple non-technical language and the objects employed, such as 'string', 'rods', 'wheels', etc., were of a kind known to all subjects. They were read over with the younger children, while older subjects were invited to ask for explanation of any doubtful word or phrase. The various parts of the mechanisms employed were shown in outline in the diagram, and no technicalities were involved here. In carrying out (*c*) above it was not necessary to visualize, or even to conceive the objects in all their concrete detail, for the spacial characters and relations about which the subject was called upon to think were given in the lines of the diagram—these lines themselves provided the material for thought. It was necessary, however, to associate with the lines such simple properties of the objects they represented as entered into the problems—to remember that this line (a 'rod') was rigid, that line (a 'string') could be twisted about, that circle (a 'wheel') could turn, etc. We found that quite young children could do this.[1]

With one reservation, the work of this stage does not appear to involve those processes which seem specially associated with the *m* factor, but depends rather on general mental development and 'intelligence'—influences reduced to a minimum by the homogeneity of our groups and the precautions as regard 'training' already mentioned. Judging from questions put to the children, and from the introspections, it caused no difficulty and occupied but a brief interval of time, the real work of the test being that of the last stage. The reservation occurs in the case where the mechanism is sufficiently complex to render the description itself difficult to follow. Here the diagram and the description help each other out, and in so far as this occurs, the aid derived immediately from the diagram will depend, in large measure, on those processes which seem directly connected with the *m* factor.[2]

Second Stage. Here the subject is called upon to do precisely the same kind of work as in 'testing the method' in

[1] Much younger children than any of our subjects were able to name various parts from merely seeing such diagrams. A girl of 3½ years was able to point out 'string', 'wheel', and what she called 'scales', etc.

[2] Such a case is provided in the 'mechanical diagrams' test, and is considered more fully in that connection (page 204).

the models test.[1] In both cases the resulting effect on a series of linked items when one of their number is operated in a given way must be cognized. The analysis of this operation has already been given with respect to the 'models' test. The two cases differ, of course, with respect to the degree of knowledge of the various parts of the mechanism with which the subject approaches his task, and his ultimate object in 'testing' them, for in one case he is inquiring into the working of a mechanism of his own devising with a view to seeing whether it works as required, in the other into one that someone else has devised, with a view to seeing how it works.

C. Analysis of 'Mechanical Completion' Tests

What has been said with regard to the first stage of the 'explanation' tests applies to this test also, the problem being presented here, as in the former test, by means of a diagram and description involving simple notions with which all subjects would be familiar. In so far as any special ability enters into this initial task of making clear the problem, it would seem to reside in a readiness to keep in mind those same spacial characters and relations of the various parts depicted in the diagram which we have already had occasion to examine, and by means of which meaning and reality is given to the otherwise empty lines. Such special cognitive ability, however, hardly appears to enter to any appreciable extent in the relatively simple diagrams we employed.

The important work lies in solving the problem. Here the subject is faced with the same kind of question as in the 'models' test,—how to devise a mechanism to fulfil some definite purpose. Consequently the work follows a similar course and involves the same cognitive processes as we have already examined. The two tests, however, differ with respect to the general setting of the problem, for the 'models', although made of concrete material, deal with relatively abstract movements, while the 'completion' tests are concerned with concrete problems, such as the moving of trolleys, the turning of wheels, the putting on of brakes, etc. Hence considerations regarding the practical suitability of the links

[1] See page 152.

employed are more likely to arise in the latter test and to determine the choice of method. But these are of the simple 'everyday' kind needing no technical knowledge.

D. Analysis of 'Mechanical Diagrams' Tests

First Procedure. The mental work falls into two parts, viz. (1) making clear the nature of the various items constituting the mechanism depicted in the diagram,[1] and (2) determining the particular function of these items. But these hardly form distinct stages on account of their close interdependence. This arises from the fact that the knowledge involved in (1) must be gleaned entirely from the diagram, there being, in this test, no accompanying description, and such knowledge is derived not only from the shapes of the items themselves, but also from those relations between them which determine their function, as cognized in (2): what any particular part is intended to do is a clue to what it is intended to be, and vice versa. An interesting case of this was provided by the infant girl of 3½ years already referred to.[2] Asked what one of the parts in a diagram was, she replied, 'a wireless', obviously from its resemblance to a basket coil which she had seen her brothers making some time previously. Had she been able to see its functional relation to the other parts of the diagram, and particularly its relation to the string which passed round it, she would have known it to be a wheel.[3] The same fact came to light in the introspections and in the observations of other children to whom the diagrams were shown. It is evident from the former that when first presented with the diagrams it was a natural impulse to consider how the mechanism as a whole functioned, while the children—especially the weaker ones at this kind of test—were apt (wrongly) to decide, from its general appearance, what it was 'for', before they had really seen how it worked.

[1] Not their technical names or properties, but merely whether a 'wheel' 'pipe', 'rod', etc.

[2] In the footnote on page 202.

[3] That the failure was not due to inability to cognize 'wheel' as such was shown by her success at pointing out wheels represented by precisely similar outlines when asked to do so.

Briefly, the cognitive work involved in (1) consists in cognizing the shapes of the various items, and the space relations between them, together with reproductive knowledge of how simple objects like rods and wheels respond to force. After having decided on the nature of the parts, the work of (2) follows the same course as that of 'testing the method' in the 'models' test, and stage 2 of the 'explanation' test: the correlative movements set up in the other links when the operating item moves must be educed. But as the other items are not described in the presentation, there tends to remain some element of doubt as to whether they have been rightly cognized, until both the item and the movement it is thought to carry out fit together satisfactorily—a feature which leads to the cross-reference between (1) and (2) to which we have referred, and which is absent in the other tests.

Second Procedure. In this procedure, found necessary with the younger elementary school groups, the names of the various items forming the mechanism were enumerated by the experimenter. This had the effect of simplifying the task, the knowledge sought in (1) above being largely given in these names. The test, as then presented, tended to be more like the 'explanation' test, though not entirely so, since this verbal enumeration of parts did not provide so full a description as was given in the latter test, and left a certain amount of the work of (1) to be done by the subject.[1] The effect of this change in procedure was to give the children—who found the first procedure too difficult—something more definite to go on, thus leaving less room for guess-work and so securing greater reliability.

III. METHOD OF DETERMINING THE CORRELATION OF A TEST WITH m (r_{am})

The method is the same as that employed by Spearman for determining the correlation with g. Let r_{ab}, r_{ac}, r_{bc} be the *specific* inter-correlations between three m tests, i.e. the correlation which they have with each other on account of

[1] The diagrams, too, differed in type, bearing in the diagrams test, a closer resemblance to real mechanical apparatus.

m, the influence of g having been eliminated by Yule's method of partial correlation. Then by Yule's theorem,
$r_{ab.m} = (r_{ab} - r_{am} \cdot r_{bm})/(1 - r_{am})^{\frac{1}{2}}(1 - r_{bm})^{\frac{1}{2}}$.
By assumption, $r_{ab.m} = 0$, hence $\qquad r_{ab} = r_{am} \cdot r_{bm}$
Similarly, taking $r_{ac.m}$, and $r_{bc.m}$, $\qquad r_{ac} = r_{am} \cdot r_{cm}$

$$r_{bc} = r_{bm} \cdot r_{cm}$$

By multiplying the first equation by the second, dividing by the third, and taking the square root of each side,—

$r_{am} = (r_{ab} \cdot r_{ac}/r_{bc})^{\frac{1}{2}}$, and similarly for r_{bm} and r_{cm}.

Other determinations of r_{am} may be obtained by taking as b and c every other available pair. To get the most probable value of r_{am} these determinations are averaged, either arithmetically, or by the following more reliable method :—

$$r_{am} = \frac{r_{ab} \cdot r_{ac}}{r_{bc}} = \frac{r_{ab} \cdot r_{ad}}{r_{bd}} = \ldots = \frac{r_{ax} \cdot r_{ay}}{r_{xy}}$$

$$= \frac{r_{ab} \cdot r_{ac} + r_{ab} \cdot r_{ad} + \ldots + r_{ax} \cdot r_{ey}}{r_{bc} + r_{bd} + \ldots + r_{xy}}$$

Determinations for r_{bm}, r_{cm}, etc., are made in a similar fashion.

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